Volume 18 APRIL, 1948 Number 1

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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PLATES 1–2, FIGS. 1–2, APRIL, 1948

MICROSTYLOLITES IN SANDSTONE

LAURENCE L. SLOSS
Department of Geology, Northwestern University, Evanston, Ill.
AND
DAN E. FERAY
Department of Geology, University of Wisconsin, Madison, Wis.

ABSTRACT

Stylolites developed on a microscopic scale along grain boundaries were found in the chert facies of the Cut Bank sandstones, Cut Bank Oil Field, Montana, and the interpenetrating columns of chert and dark residue along the seam are similar to other stylolites. Associated with the microstylolites are quartz grains imbedded in chert grains and secondarily enlarged quartz grains. The development of microstylolites and enlargement of quartz grains has affected the porosity and permeability of the producing horizon in the Cut Bank Oil field. The authors view the evidence here presented as support to the pressure-solution theory of origin of stylolites.

INTRODUCTION

The occurrence of stylolites in sedimentary rocks has received attention from geologists from standpoints of curiosity, relation to diagenesis, stratigraphic significance, and general sedimentational interest. Study of stylolites in terms of their possible economic significance has been neglected because of the general unimportance of these structures in connection with most economic aspects of sedimentary rocks.

This paper presents a hitherto unreported form of stylolites and suggests their economic significance as contributing to reduction of porosity and permeability of a sandstone by the development of stylolites at boundaries between grains of chert and between grains of chert and quartz.

Data for the paper were derived from microscopic study of producing sands in the Cut Bank oil and gas field, Glacier County, Montana, as part of an intensive investigation by the Montana Bureau of Mines and Geology of the geologic factors governing reservoir performance in the field.

ACKNOWLEDGMENTS

To the Montana Bureau of Mines and Geology, and particularly to Francis A. Thomson, Director, and Eugene S. Perry, Chief Geologist, the writers are indebted for assistance and encouragement during the investigation. Part of the material here presented was obtained in 1941 when Mr. Feray was the recipient of research grants from the Glacier Production Company. Ray Gallant was a co-worker in the research and contributed much valuable data. Others who materially aided the project by adding valuable data, samples, and ideas were J. E. Hupp, Cut Bank, Montana; J. H. McCourt, Union Oil Company of California, Cut Bank, Montana; and J. E. Blixt, the Texas Company, Shelby, Montana. For valuable concepts concerning the origin and significance of the stylolites, and for

critical reading of the manuscript, the writers are indebted to W. H. Twenhofel and S. A. Tyler of the University of Wisconsin, to W. C. Krumbein and E. C. Dapples of Northwestern University, and P. B. Stockdale of the University of Tennessee.

TYPES OF STYLOLITES

Stylolites occur most commonly in limestones (1) and less commonly in quartzite (2, 3), sandstone (4), and gypsum (5). All these recorded stylolites are megascopic and observable in the field. The stylolites discussed in this paper are of microscopic dimensions and are confined to boundaries between sand grains.

A thorough review of the theoretical origin of stylolites is available (6, 7, 8, 9). As far as the writers are aware, there is no reference in the literature to intensive development of stylolites of microscopic character at the contact of grain boundaries in a sandstone. This type of lithic structure has undoubtedly been observed by other geologists, but such structures may not have been developed elsewhere to the pronounced degree found in the Kootenai sandstone of the Cut Bank field. Stylolites of microscopic size have been observed by Stockdale who has called attention to miniature stylolites (6), to the minuteness of stylolites along the solution contacts between pebbles of the Potomac marble (8), and to stylolites in quartzite of "almost microscopic" size (3). Stockdale (7) has called attention to Sorby's discussions of 1863 on the development of stylolite features at the contacts between pebbles. Reference was also made by Stockdale to the work of Reade in 1895 on the origin of stylolite-like structures at contacts of quartzite pebbles in the Bunter conglomerate. The latter occurrence is similar to that here described with the exception that the stylolites in the Cut Bank sands are between grains of sand size. Waldschmidt briefly referred to imbedded sand grains in shale fragments and mentioned the "imbedding" as the probable result "of existing pressures and of recrystallization of the calcite contained within the shale." The related feature of interlocking quartz occurs abundantly in many sandstones and is well described by Waldschmidt.

LITHOLOGY OF THE KOOTENAI SANDSTONE AT CUT BANK

The Cut Bank oil and gas field is located in northern Montana and its relation to associated structural features is shown in Figure 1. The geology of the Cut Bank oil and gas field has been described in several papers, most recently and comprehensively by Blixt. The stratigraphic position of the Kootenai sandstone (Lower Cretaceous) in the Cut Bank field is shown in Figure 2. The formation is described by Blixt as follows:

> In the Cut Bank field, the Kootenai (Lower Blairmore) is 500 feet thick on the east, and increases to 650 feet on the west. The whole formation is a hodgepodge of flood-plain and deltaic deposits consisting of red, green, and gray mudstones and shales, and lenticular siltstones and sandstones. The lower third of the formation contains more sandstone than the upper two-thirds and here lie the various oil and gas-producing sandstones in the field.

The sandstones vary in lithology both vertically and laterally. In general, the upper two sandstones, the Sunburst sand and Upper Cut Bank sand, consist essentially of quartz with a minor quantity of chert and there is a pronounced development of secondary enlargement of quartz grains. The third unit, the Lower Cut Bank sand, is composed of quartz and chert. The striking development of microstylolites occurs in the Lower Cut Bank sand.

The mineral suite in the Cut Bank sands and conglomerates includes quartz, chert, tourmaline, zircon, leucoxene, barite, calcite, pyrite, magnetite, kaolinite,[1] siderite, and an unknown green mineral resembling glauconite but lacking potas-

[1] The kaolinite occurs in large enough quantities to be identified by both optical and x-ray methods. The carbonates were determined by chemical and optical properties.

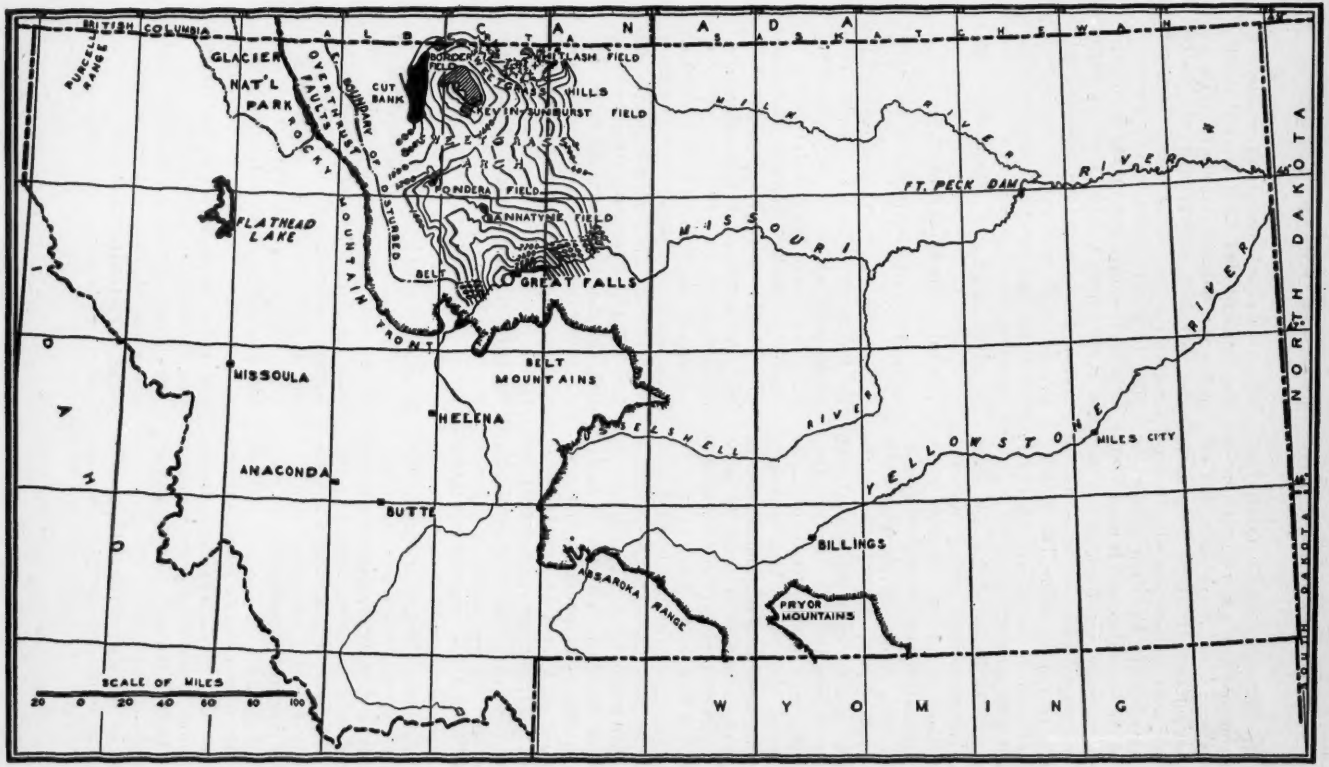


Fig. 1—Map of Montana showing location and regional structural setting of Cut Bank field and its relation to other fields of Sweetgrass arch. July 1, 1940. Reproduced from J. E. Blixt, "Cut Bank Oil and Gas Field," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol., 1941.

sium (possibly greenalite). Quartz and chert compose more than 90 per cent of the sandstone, and heavy minerals form only insignificant fractions. In general, the chert content decreases with increasing stratigraphic elevation above the base of the formation, and is most abundant in the Lower Cut Bank sand, where, with lateral variability, it forms from 20 to 90 per cent of the grains. The Sunburst sand, in contrast, has an average quartz content of 90 per cent.

The quartz grains of the Cut Bank sand characteristically exhibit secondary enlargement by addition of silica in optical orientation with the original detrital grains, some grains having excellently developed crystal faces. Where the "ghosts" of the original grains are visible in thin sections (Plate 2, figure 6), they indicate a high degree of sphericity and roundness. Moderately high sphericity and roundness, plus occasional frosting, is also characteristic of grains in nitric acid residues from pyritized portions of the Lower Cut Bank sand.

The chert grains in the Cut Bank sandstones exhibit many interesting phenomena. The grains range in size from very fine sand to pebbles, with low to moderate roundness and sphericity, and superficially homogeneous black color in reflected light. By transmitted light, the chert grains vary from opaque to translucent and the non-opaque grains commonly have a fine granular mosaic texture with aggregate polarization under crossed nicols. Black chert grains with lighter colored centers are found occasionally, and many organic remains may be observed, including sponge spicules and radiolaria. The normal spherulitic pattern of chert is also present. The texture of the chert grains is generally microcrystalline, but some grains are breccia-like, larger particles in a microcrystalline ground mass, coquina-like and cryptocrystalline. Many of the grains are cut by a net work of fractures filled by secondary silica.

Calcite, siderite, pyrite, and kaolinite occur as cementing materials or void-fillings between other grains. Pyrite has also replaced chert to a marked degree and was evidently introduced prior to the secondary enlargement of quartz grains. The carbonates were introduced prior to kaolinite and occupy positions between the latter mineral and the quartz or chert grains. Calcite occurs as single isolated grains filling interstices, and siderite as fine rhombic particles along grain boundaries and as a cementing material which usually is brown in color. Kaolinite is present along grain boundaries where carbonates do not intervene and as rounded masses filling interstices.

MICROSTYLOLITES IN THE CUT BANK SANDS

Microstylolites have been observed in the Lower and Upper Cut Bank sandstones and, less commonly, in the Sunburst sandstone. The structures occur in coarse- to medium-grained sandstones with a chert content ranging from 20 to 90 per cent. The most spectacular development of typical stylolitic seams of microscopic size is found in the Lower Cut Bank sandstone, the member of highest chert content. The microstylolites are best developed normal to the bedding, although random orientations occur. The structures develop at points of contact between chert and quartz grains and between grains of chert, development in the latter situation being the more pronounced. The type of penetration of grains is governed by the grains involved, and contact between interpenetrating grains is marked by a black seam consisting of insoluble residue from the dissolved portions of the respective grains. The length of a stylolitic seam, as seen in thin-section, increases with increasing grain size. Stylolites occur only along contacts involving chert grains. Typical stylolitic interpenetrations form between grains of chert, whereas contacts between chert and quartz grains are marked by imbedding of the quartz into the chert.

Stylolites produced between chert grains are characterized by sharp, irregular, mutually penetrating columns, with a clearly marked seam of insoluble

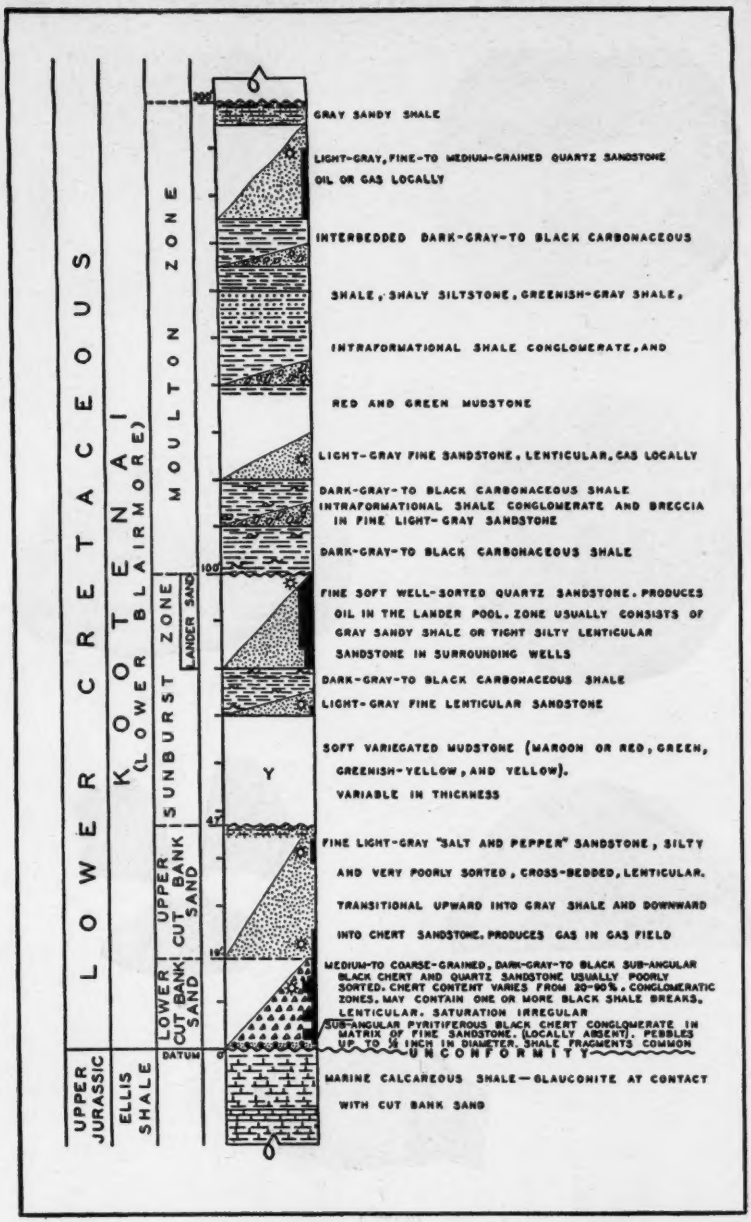
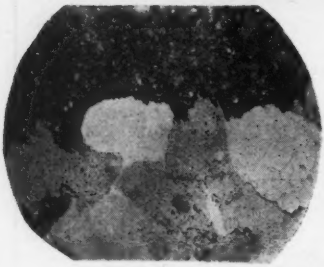

LOWER CRETACEOUS
KOOTENAI (LOWER BLAIRMORE)
MOULTON ZONE
SUNBURST ZONE
LANDER SAND
UPPER CUT BANK SAND
LOWER CUT BANK SAND
DATUM
UPPER JURASSIC
ELLIS SHALE
GRAY SANDY SHALE
LIGHT-GRAY, FINE-TO MEDIUM-GRAINED QUARTZ SANDSTONE OIL OR GAS LOCALLY
INTERBEDDED DARK-GRAY-TO BLACK CARBONACEOUS SHALE, SHALY SILTSTONE, GREENISH-GRAY SHALE, INTRAFORMATIONAL SHALE CONGLOMERATE, AND RED AND GREEN MUDSTONE
LIGHT-GRAY FINE SANDSTONE, LENTICULAR, GAS LOCALLY
DARK-GRAY-TO BLACK CARBONACEOUS SHALE INTRAFORMATIONAL SHALE CONGLOMERATE AND BRECCIA IN FINE LIGHT-GRAY SANDSTONE
DARK-GRAY-TO BLACK CARBONACEOUS SHALE
100'
FINE SOFT WELL-SORTED QUARTZ SANDSTONE. PRODUCES OIL IN THE LANDER POOL. ZONE USUALLY CONSISTS OF GRAY SANDY SHALE OR TIGHT SILTY LENTICULAR SANDSTONE IN SURROUNDING WELLS
DARK-GRAY-TO BLACK CARBONACEOUS SHALE
LIGHT-GRAY FINE LENTICULAR SANDSTONE
SOFT VARIEGATED MUDSTONE (MAROON OR RED, GREEN, GREENISH-YELLOW, AND YELLOW). VARIABLE IN THICKNESS
Y
FINE LIGHT-GRAY "SALT AND PEPPER" SANDSTONE, SILTY AND VERY POORLY SORTED, CROSS-BEDDED, LENTICULAR. TRANSITIONAL UPWARD INTO GRAY SHALE AND DOWNWARD INTO CHERT SANDSTONE. PRODUCES GAS IN GAS FIELD
MEDIUM-TO COARSE-GRAINED, DARK-GRAY-TO BLACK SUB-ANGULAR BLACK CHERT AND QUARTZ SANDSTONE USUALLY POORLY SORTED. CHERT CONTENT VARIES FROM 20-90%. CONGLOMERATIC ZONES. MAY CONTAIN ONE OR MORE BLACK SHALE BREAKS. LENTICULAR. SATURATION IRREGULAR
SUB-ANGULAR PYRITIFEROUS BLACK CHERT CONGLOMERATE IN MATRIX OF FINE SANDSTONE. (LOCALLY ABSENT). PEBBLES UP TO ¼ INCH IN DIAMETER. SHALE FRAGMENTS COMMON
UNCONFORMITY
MARINE CALCAREOUS SHALE—GLAUCONITE AT CONTACT WITH CUT BANK SAND

Fig. 2.—Generalized composite section showing producing zones, Cut Bank field, Reproduced from J. E. Blixt, "Cut Bank Oil and Gas Field," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol., 1941.



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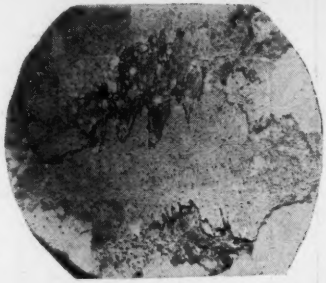

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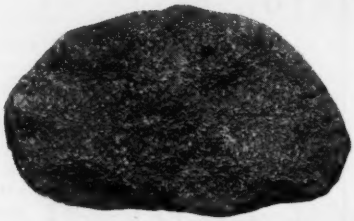

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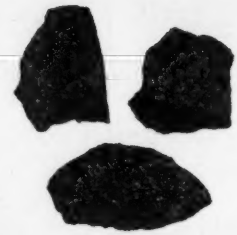

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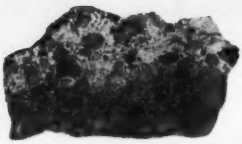

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PLATE 1

(Explanation on facing page)

residue. Considerable reduction in size of chert grains by solution during stylolite formation is common and often large portions of the participating grains are lost. Variations in texture and color of chert grains, irregularity of seams, and the dark residue, all contribute to ease of recognition of the stylolites.

Stylolites between quartz and chert grains are characterized by a general imbedding of the quartz grains into the chert, forming a seam without stylolitic columns and usually much more regular than the seams between chert grains. There are exceptions to this smooth imbedding of quartz into chert, however, and occasionally short, irregular interpenetrating columns of quartz and chert are found. An explanation for these variations in behavior may be sought in the variable character of the chert.

The seam marking interpenetrating grain contacts varies in thickness with the volume of the dissolved portions of participating grains and their content of insoluble matter. Where quartz and chert grains are involved, the chert grain alone has contributed the insoluble matter. All seams are opaque and are generally thickest at the ends of the stylolitic columns.

ORIGIN OF THE MICROSTYLOLITES

The Cut Bank field lies approximately 50 miles east of the Lewis Thrust exposed at Glacier National Park and approximately 27 miles east of the eastern limit of the "disturbed belt" of complex structure which characterizes the foothills and adjacent plains along the Northern Rocky Mountain front. In the Cut Bank field the Cut Bank sands are beneath 3000 feet of sediments which may have exceeded 5000 feet prior to late Tertiary and Quaternary erosion. Thus, stresses resulting from both diastrophism and load have been operative, affecting the low-grade dynamic metamorphism of the Cut Bank sands. Differential solution of the chert grains at points of contact has resulted in (1) removal of silica by solution of chert, (2) interpenetration of chert grains, (3) imbedding of quartz in chert grains, and thus producing typical stylolitic seams on a microscopic scale. It seems apparent that the capacity of the chert to undergo differential solution at points of contact under pressure is due

EXPLANATION OF PLATE 1

PLATE 1. MICROSTYLOLITES AND CORE SAMPLES

FIG. 1. Microstylolitic intergrowth of chert grains and penetration of quartz grains into chert grains. The uppermost grain is a chert pebble. Note the difference in the type of pattern produced by the chert-chert contacts and the chert-quartz contacts. Note the opaque material along the stylolitic seam. Lower Cut Bank sandstone, core from Santa Rita Lundren #2, ×40.

FIG. 2. Microstylolitic intergrowth of chert grains showing excellent development of the stylolitic columns. Note the smooth outline of imbedment of the quartz grain into a chert grain in the lower right corner of the photograph. Lower Cut Bank sandstone, core from Santa Rita—Lundgren #2, ×40.

FIG. 3. Upper Cut Bank "salt and pepper" sandstone showing mixture of quartz and chert grains. Core sample from Cut Bank Oil field. Approximately natural size.

FIG. 4. Sunburst sandstone showing characteristic high content of quartz and absence of chert grains. Core from Santa Rita Lander #1. Approximately natural size.

FIG. 5. Coarse-grained Lower Cut Bank sandstone showing the high content of chert grains and low content of quartz grains that occurs in this sand stone. Core from Cut Bank Oil Field. Approximately natural size.

FIG. 6. Lower Cut Bank sandstone showing dark color of the sandstone as produced by the high chert content. These samples consist of about ninety per cent chert and ten per cent quartz and kaolinite. This sample is from a high productive zone of the Cut Bank Oil field, yet the sandstone is not friable due to the cementing effect of the microstylolitic intergrowths. Core from Cut Bank Oil field. Approximately natural size.

FIG. 7. Chert conglomerate from the Lower Cut Bank sandstone. The lower portion of the sample is pyritized. Core from Cut Bank Oil field. Approximately natural size.

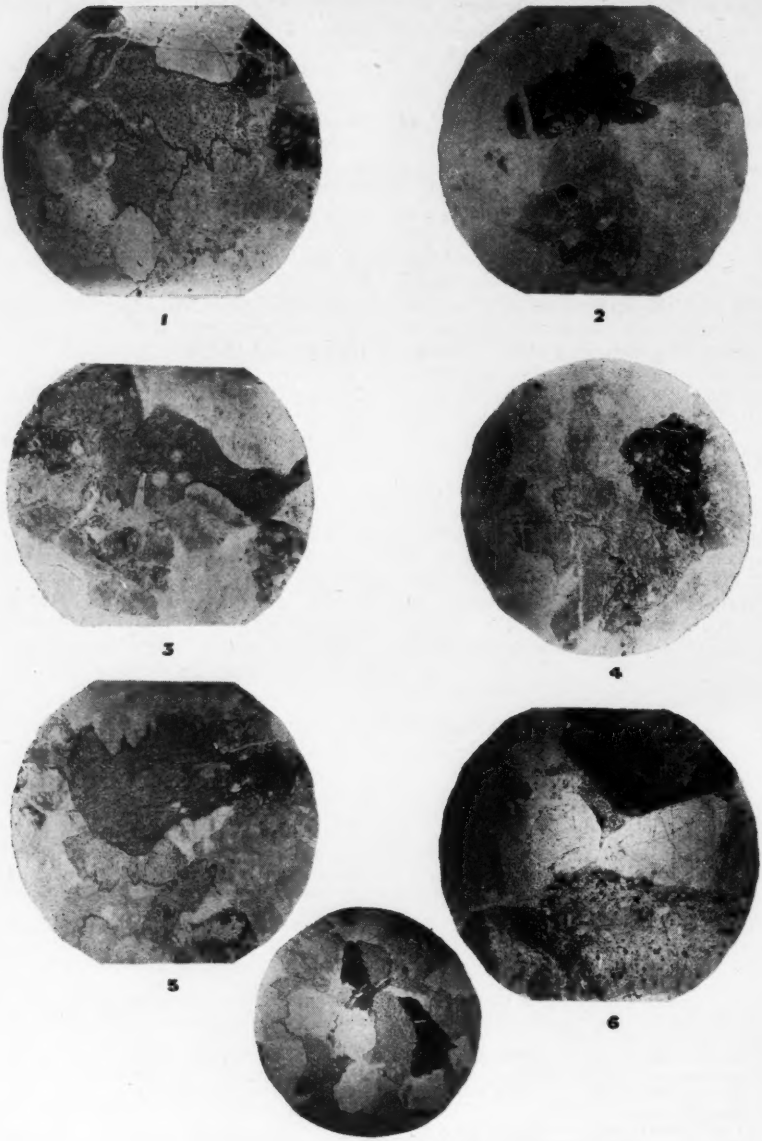

PLATE 2

(Explanation on facing page)

to variations in texture, composition, and included matter of the chert grains. The development of stylolites by solution of silica from chert grains was accompanied by redeposition of the silica on quartz grains at points of least pressure, resulting in the pronounced secondary enlargement of the quartz grains. Although a relatively large quantity of silica was made available for quartz enlargement by chert solution, it does not follow that all such enlargements in the Cut Bank sands were the result of this process, since other contributions were probably made from connate and other ground waters. The microstylolites are best developed normal to the bedding and it is the writers' opinion that the load of overlying sediments was the chief factor in pressure-solution, and that diastrophic stresses, though effective, played a less important role.

A concept well founded in metamorphic geology is that of solution of minerals at points of contact and deposition of the dissolved material at points of less pressure when the rock is under dynamic pressure. The subject is well discussed by Harker under the discussion of Reikie's principle. This concept seems clearly displayed in the development of microstylolites in the Cut Bank sandstones. However, as pointed out by Dr. Stanley Tyler in personal discussions, the environment of solution of silica at points of contact is not closely associated with the environment of deposition of the silica. The solution of silica from the chert took place to the greatest degree in the Lower Cut Bank sandstone where chert is predominant; the deposition of most of the silica to the greatest degree in the Upper Cut Bank sandstone where quartz is more abundant. One requisite for deposition of silica in solution seems to be a quartz grain, and not simply an area of lower pressure in the pore spaces associated with the grains undergoing solution. Since the chert grains consist of many very small crystals of quartz, mineralogically the chert should be a favorable host to deposition of silica in the associated pores, yet such is not the case. The reason silica is not deposited on the chert is due possibly to the fact that a chert grain composed of myriad quartz grains of ultramicroscopic size in all possible optical orientations, represents in itself no definite optical orientation, whereas any quartz sand grain has a single definite optical orientation and consequently more strongly induces deposition of the silica.

Sandstones of the Cloverly formation (Northern Wyoming equivalent of the Kootenai) described by Waldschmidt

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EXPLANATION OF PLATE 2

PLATE 2. MICROSTYLOLITIC INTERGROWTHS

FIG. 1. Stylolitic pattern developed between chert grains and contrasting imbedment of quartz grains into chert grains. Note difference in color and texture of the chert grains. Lower Cut Bank sandstone, ×40.

FIG. 2. Stylolitic pattern developed between chert grains in the Lower Cut Bank sandstone. Core from Santa Rita Rasmussen #1, ×40.

FIG. 3. Stylolitic pattern and imbedment of quartz grains into chert. Lower Cut Bank sandstone, ×40.

FIG. 4. Typical development of microstylolites in the Lower Cut Bank sandstone. Core from A. B. Cobb Walburger #7, ×40.

FIG. 5. Typical development of microstylolites in the Lower Cut Bank sandstone. Core from A. B. Cobb Walburger #7, ×40.

FIG. 6. Quartz grains showing secondary enlargement. The rounded original quartz grains can be easily seen. Note the development of crystal faces by the secondary quartz. The fine material between the chert and quartz grains in the left portion of the picture is kaolinite. This illustrates the filling of interstices by kaolinite and enlargement of the quartz grains. Upper Cut Bank sandstone, ×40.

FIG. 7. Typical development of microstylolites in Lower Cut Bank sandstone, ×20.

contain chert in quantities varying from minor amounts to abundant, yet the stylolitic pattern is not developed, even though the sandstones have interlocking quartz grains resulting from solution at points of contact. Similarly, examination of other chert-rich Cretaceous sands of the northern Rocky Mountain province has not yielded examples of stylolitic interpenetration of grains, although in many places the sands have been subjected to greater stresses of load and deformation than those acting upon the Cut Bank sands. It seems probable, therefore that the development of microstylolites in sandstones requires the coincident application or occurrence of at least three factors:—susceptible mineral grains; stress of overburden or deformation (or both); and certain undetermined chemical attributes of the enclosed waters. Apparently these conditions were satisfied in the case of the Cut Bank sands, but similar coincidences may not be expected to be of common occurrence.

CONCLUSIONS

The Cut Bank sandstones of the Cut Bank field consist predominantly of a mixture of quartz and chert grains. These sandstones have been subjected to pressures of both dynamic and load types in the presence of solutions capable of assisting in the solution and transportation of silica. Such conditions have led to the removal of silica from chert grains at points of contact, and deposition of the silica as secondary enlargement of quartz grains. The resulting sandstone is firmly cemented and can be referred to as semi-quartzitic, yet has highly variable porosity and permeability. The development of microstylolites and the secondary enlargement of quartz have combined to reduce the primary porosity and permeability of the sands to such a degree as to control the accumulation, and thus the production, of oil and gas. In the Lower Cut Bank sand, those zones and lenses having the highest chert content and greatest stylolitic development have the highest porosity and permeability. This apparent paradox is explained by the fact that quartz enlargement is the dominant factor in reduction of reservoir potentialities in the Cut Bank sands. Silica removed during stylolite development in the chert-rich zones has migrated to quartz-rich zones where the more favorable environment for precipitation and secondary enlargement prevailed. Thus, the chert-rich zones have been adversely affected by the relatively minor process of compaction by interpenetration of grains, whereas the quartz-rich zones have suffered the pore-obliterating process of secondary enlargement. This relationship clarifies the known dependence of Lower Cut Bank reservoir performance on chert content and contributes to the explanation of the erratic and unpredictable production potentials encountered throughout the field.

Although the type of stratigraphic trap at Cut Bank is still the subject of debate, the major accumulation of oil and gas can not be accounted for by the processes here described. Development of stylolites and secondary enlargement have at least partially controlled the location of barren and productive areas within the field, however, and the same twin processes may possibly be responsible for stratigraphic traps elsewhere.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 1, PP. 14–23
FIGS. 1–2, PLATE 1, APRIL, 1948

A CODE FOR EXPRESSING GRAIN SIZE DISTRIBUTION[1]

K. O. EMERY
Geology Department, University of Southern California, Los Angeles, California
AND
HOWARD GOULD
Scripps Institution of Oceanography, La Jolla, California

ABSTRACT

The necessity for quickly analyzing and plotting large suites of marine bottom samples has resulted in the development of a new coding method for expressing grain size distribution. The system gives reasonably accurate estimates of the median diameter, skewness, and sorting coefficient. Grain diameters either in microns or in the phi notation can be obtained from the code.

INTRODUCTION

During the war a large part of the effort of the University of California Division of War Research was spent on a study of the transmission of sound in the ocean. Two of the factors controlling the transmission of sound in shallow water were found to be the topography and the composition of the sea floor. In order to evaluate these factors, a large number of bottom samples, soundings, and underwater photographs were collected, primarily from depths less than 100 fathoms. Large collections from several areas promise to yield much new information regarding the effects of currents, temperatures, source areas, and submarine topography on the composition of continental shelf-sediments. Following this report on methods of sediment study, a number of reports are planned for specific areas, describing the sediments and their relationship to environments. Some of the more interesting results obtained by use of the underwater camera off California have already been reported by Shepard and Emery (1946), and more details on the handling and processing of the samples and associated data are given in a University of California Division of War Research report (Emery, 1946).

COLLECTION OF SAMPLES

Of the more than 4000 bottom samples collected, about 60 per cent were obtained with an underway sampler of the type described by Ewing, Woollard, Vine, and Worzel (1946) or by an improved model called a "mousetrap" (pl. 1, fig. 1) which was devised at Woods Hole Oceanographic Institution. A further modification of this sampler was used toward the close of the investigation. All of the underway samplers operate on the same general principle. They are lowered by a high-speed winch on a light wire cable from a ship moving at speeds up to about 12 knots. A heavy forward end and fins at the after end cause the sampler to sink nearly vertically through the water. When the sampler strikes bottom, the wire slackens appreciably, and the winch then hauls the sampler back aboard ship. The sample is protected from washing by a door which closes over the cup opening when the device strikes bottom. This sampler recovers only about 20 to 50 grams of sediment but that quantity is sufficient for most analyses, unless the

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FIGURE 1

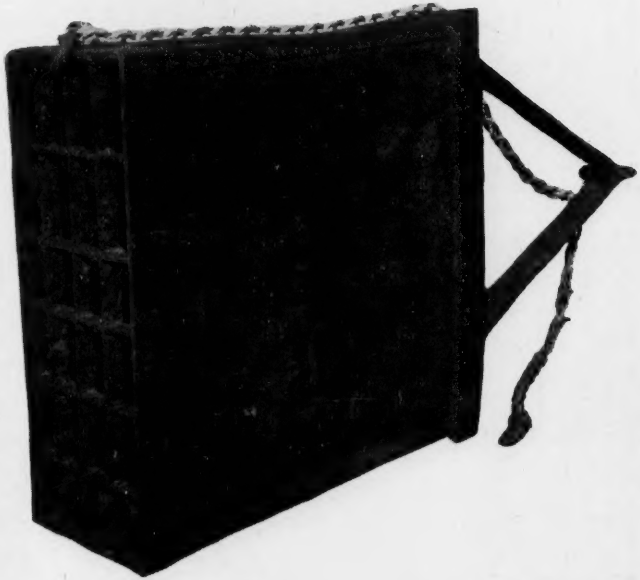

FIGURE 3

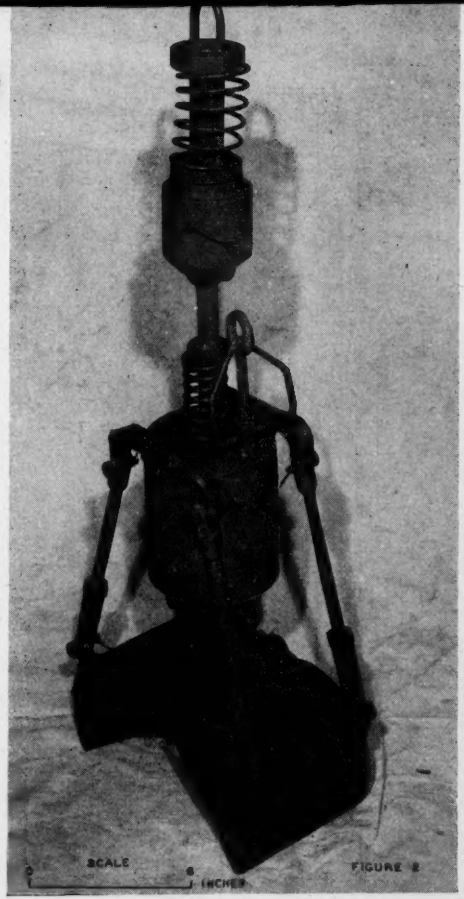

FIGURE 2

PLATE 1

FIG. 1. "Mousetrap"—underway bottom sediment sampler devised at Woods Hole Oceanographic Institution.
FIG. 2. Snapper sampler designed to trip when the lowering cable slackens and to close when the cable begins to hoist.
FIG. 3. Heavy dredge for collecting large rock samples.

sample happens to be very coarse-grained. Freshly broken chips of rock have frequently been obtained. The principal advantage offered by use of the underway sampler is the saving in sampling time, since it is not necessary to repeatedly stop and start the ship. Moreover, the samples can easily be correlated with topography, which may be recorded simultaneously by a continuously recording echo-sounding tape.

Most of the remaining samples were obtained by a snapper (pl. 1, fig. 2) which is designed to trip when the lowering cable slackens as the device strikes bottom. When the cable is reeled in again, the sampler closes automatically. This tripping mechanism was found especially useful for sediments too soft to activate the foot-like trigger used on some other samplers. The advantage of this device is the large size of the sample obtained, sometimes as much as one kilogram. More time per sample is required, however, because the ship must be stopped or slowed to less than 5 knots for satisfactory performance; also, when the ship is rolling heavily, the device may close while being lowered.

A number of samples, including most of those containing rocks, were collected by a dredge devised by F. P. Shepard (pl. 1, fig. 3). Masses of rock and gravel in several hauls weighed as much as 100 kilograms, and individual fragments had lengths up to about 60 centimeters. Considerable time, however, is required for each dredging, so that usually not more than about 10 samples can be dredged per day.

A few samples were obtained by miscellaneous devices including corers, small clam-shell snappers, and even ship anchors. Occasionally, a bathythermograph or some other instrument also brought up a small sample, accidentally caught by a projecting part of the mechanism.

LABORATORY STUDY OF SAMPLES

Filing of Samples—

The bottom samples were catalogued and vialed for filing at the sediment laboratory. Most of those taken by an underway sampler were just large enough to be put into a 15 cubic centimeter vial. Larger samples were quartered down by a Jones type sample splitter, the vial filed with the smaller samples for reference, and the remainder stored for mechanical and other analyses. Large rocks were filed separately.

Method of Analysis—

More than 4000 samples of sediment were available for mechanical analysis. To sieve and pipette all of them would have required thousands of man-hours, a prohibitive amount of time. It was possible to make complete mechanical analyses of some selected samples; but, if only a few were studied, information on the continuity and lateral gradations of bottom materials would be lacking. A third alternative was to sieve and pipette some of the samples and to use these samples as standards for estimating the size distribution of the remainder. Following this practical compromise, about 10 per cent of the bottom samples, selected more or less at random in each area, were accurately analyzed by sieves and pipette. Cuts of each analyzed sample were placed in glass vials which carried labels indicating the size distribution. These vials were arranged in a gradational series, somewhat like the series of refractive index oils used in mineral grain microscopy.

The remaining 90 per cent of the samples were analyzed by comparison with the standard series. Each unknown sample, also in a glass vial, was compared in turn with each standard vial until the correct region of the standard series was found. Small quantities of the unknown and of the standards in question were poured on a millimeter grid tray and the final comparison was made with a binocular microscope. Most unknowns could thus be indicated as having the same median diameter and sorting as one of the standards, or that these parameters fell between the values for two of the standards. Occasionally, an unknown

sample had a size distribution differing so radically from the standards that it could not be satisfactorily estimated; these samples were mechanically analyzed. Most such samples were the less well sorted ones, usually containing many shell fragments or large authigenic mineral grains.

For the first area studied, considerably more than 10 per cent of the samples were mechanically analyzed but only about 25 of them were required for a series of comparison standards. Some of these standard samples could be applied satisfactorily to other areas, but most of the standards were changed for each area so that no errors due to slightly different mineral composition or sorting might result. The 10 per cent of the total number of samples mechanically analyzed for each area supplied the local replacements. The size fractions of these samples were also available for mineral grain identifications.

The main advantage of this microscopic comparison method is the speed with which samples can be studied. Once the standard series has been set up for an area, the unknown samples can be analyzed without difficulty at a rate of more than 30 per hour. This is, of course, a more rapid system than that of sieving and pipetting, or the usual microscopic methods by which large numbers of grains are measured individually (Perratt and Kinney, 1923; Dunn, 1930).

Certain objections to the general use of this method are immediately evident. A small vial filled with coarse pebbly sediment cannot contain enough individual grains to be a statistically representative sample. This objection is admittedly valid but, since the entire bottom sample collected was small anyway, the objection applies to the sampling method as well; however, only a few samples contain pebbles or cobbles—most are finer. Objection can also be raised at the other end of the size scale: the various grades of silt and clay cannot be easily recognized with the binocular microscope. It happens, however, that few of the continental shelf sediments contain much clay and even silt is subordinate in quantity to sand. Probably the major objection to the use of this microscopic comparison method is that it is subjective, particularly for samples having grain size distributions slightly different from any of the standards. An attempt, therefore, was made to reduce this factor through use of a simple method of classifying the sediments.

CLASSIFICATION OF SEDIMENTS

Previous Methods—

Ordinarily, in sediment size analyses the weight percentage of grains is expressed in terms of groups with progressively smaller diameter limits. The common limits of each group are those given in the well-known Wentworth scale (Wentworth, 1926). The analysis can be presented in histogram or cumulative curve form, but both methods are too cumbersome for plotting on charts. The general size distribution of sediments can also be expressed by three numbers: median diameter, sorting coefficient, and skewness. The latter two statistical measures are usually based on the median diameter and the two quartile diameters, all of which are ordinarily given in millimeters, microns, or in the phi notation. These parameters are mentioned only briefly here, but they have been discussed very fully by both Krumbein and Pettijohn (1938, pp. 212–267) and Twenhofel and Tyler (1941, pp. 105–120). For our special purposes there are two main objections to the use of these measures. First, it is rather difficult to find room on the charts for the three separate numbers required of each sample; and second these numbers do not show the percentage of mud, a factor believed to be important in acoustic work.

In all of the areas in which acoustic measurements were made, the navigational charts contain some notations of bottom materials. The data for the charts off California were collected by the U. S. Coast and Geodetic Survey and for those

off Mexico by the U. S. Navy Hydrographic Office. Both organizations use letter symbols for clay, mud, sand, shells, gravel, stones, and rock (Adams, 1942, fig. 189S; Bowditch, 1943, p. 41). Often an adjective denoting grain size or color is prefixed. No rigid grain-size classification is used; moreover, the samples on which the notations are based were taken only by an armed lead, a sounding lead containing a small depression filled with tallow to which a small amount of sediment adheres. Use of the standard bottom terminology of charts was considered of value in correlating our samples with the acoustic measurements because the results of the measurements could then be applied directly to other areas charted with the same methods and terminology. Also, the notations are brief, simple enough to be understood by all workers, and are readily plotted on charts, so that boundaries of sediment types can easily be delineated. For these reasons F. P. Shepard, in the early phases of the work, made an attempt to use the same terminology. It soon became clear, however, that more accurately defined size grades and weight percentages of each grade size were essential. This method was eventually given up in favor of the one described below (Emery, 1945).

Sediment Code—

The most common grain size classification, that of Wentworth (1926), is based on size limits arranged in a series according to the logarithm to the base 2 of the diameter of the grains in millimeters. The only size grades given individual sediment names are those having diameters between 1/16 and 4 millimeters. This is the size range of the various sand fractions. Other size grades are grouped, and the groups are called clay, silt, pebbles, cobbles, and boulders. The cobble and boulder grades were not needed in this study because they are not present in the small samples. A further grouping of the sand grades was made, thereby reducing the number of names and also roughly following the notations used on navigational charts (table I). The size limits of the proposed grades are a series of the logarithm to the base 4 of the diameter in millimeters, except for clay, silt, and pebbles, which combine two or more grades. This grouping resulted from the fact that in microscopic analysis it was found impossible to accurately differentiate between grades of silt and of clay, and also because pebbly samples are not very representative. Sediments composed dominantly of clay, silt, or pebbles were not common.

The resulting size classification contains only six categories, arranged in the following order: *Pebbles—Coarse sand—Medium sand—Fine sand—Silt—Clay.* The size distribution of grains in a given sample may thus be expressed by writing the percentage of each size grade in this order of decreasing diameter. Thus, sediment sample No. 2561, having the composition:

Size Grade	*Per Cent Weight*
Pebbles	0.0
Coarse sand	0.4
Medium sand	0.2
Fine sand	75.1
Silt	20.3
Clay	4.0
	100.0

may be described as follows: *0.0—0.4—0.2—75.1—20.3—4.0.* This notation can be simplified by expressing the percentage of each grade by a digit between 0 and 9. For example, the digit 4 means 40.0 to 49.9 per cent, or 45.0 plus or minus 5.0 per cent. Less than 10 per cent in any grade is ignored. The notation for sample No. 2561 is thus reduced to *000720.* A further reduction results from the use of a reference point between medium sand and coarse sand, which are defined as finer than and coarser than one millimeter respectively. The notation is then *00.0720,* or simply *0720* alone. The reference point and digits to the left need be used only when sufficient material coarser than one millimeter is present. It should be noted that fewer than 15

TABLE I. *Grain size limits and nomenclature*

Diameter in Millimeters	Wentworth's Grade Name	Grade Name for Sediment Code
	Boulders	
256		
128	Cobbles	
64		
32		
16	Pebbles	Pebbles
8		
4		
	Granules	
2		Coarse sand
	Very coarse sand	
1		
	Coarse sand	
1/2		Medium sand
	Medium sand	
1/4		
	Fine sand	
1/8		Fine sand
	Very fine sand	
1/16		
1/32		
1/64	Silt	Silt
1/128		
1/256		
1/512	Clay	Clay
1/1024		

per cent of the samples required more than four digits.

The main advantages of this sediment notation is that it indicates the size distribution more accurately than by the navigational chart nomenclature and more simply than by the use of ordinary geological terminology. It also expresses grain size distribution with an accuracy approximately equal to that permitted by standardized microscopic size analyses. The main disadvantage of the system is its radical departure from previous methods, and also that the silt grade, in particular, includes a size range comparable to the range of two of the sand grades.

RELIABILITY OF METHOD

One of the tests of any method of sediment analysis should be reproducibility. For any method there is an error in sampling, or splitting the original sample down to a size convenient for study. For sieve and pipette analysis the sample is usually large enough, 15 to 25 grams., so that a standard sample splitter can be used. With this device the error of separating an aliquot fraction of a larger sample is only a few per cent, being largest for coarse sediments. For microscopic examination only a small quantity is required, and this is obtained by pouring from a vial, probably resulting in too great a proportion of large spherical grains. In microscopic analysis the larger personal factor also can be expected to yield a larger overall error.

In order to estimate the reliability of the method, 42 samples were examined microscopically and were assigned code numbers as soon as a set of standards had been prepared. All of these samples were then sieved and pipetted and the resulting analyses were coded. The comparison of codes from mechanical and micro-

scopic analyses is shown in Figure 1. The analyses of only 2 of the 42 samples, or 5 per cent, differ by more than two units of the code number. Another indication of the reasonable accuracy of the method is presented by the general appearance of the notations plotted at the sampling sites on the charts of various areas. Generally, the notations show a fairly smooth gradation from coarse to fine when the bottom is flat or smooth. Ordinarily, there are no abrupt differences between adjacent samples even though the samples within an area were neither collected nor studied in sequence, but at random. Thus, it would seem that the error of analysis is no greater than the error of obtaining a representative sediment sample by small bottom sampling devices.

SORTING

Very well sorted samples are represented by either one digit in the code number (*0900*), or by two digits having a sum of nine (*0450*) depending on whether the limiting diameter between size grades intersects the size frequency

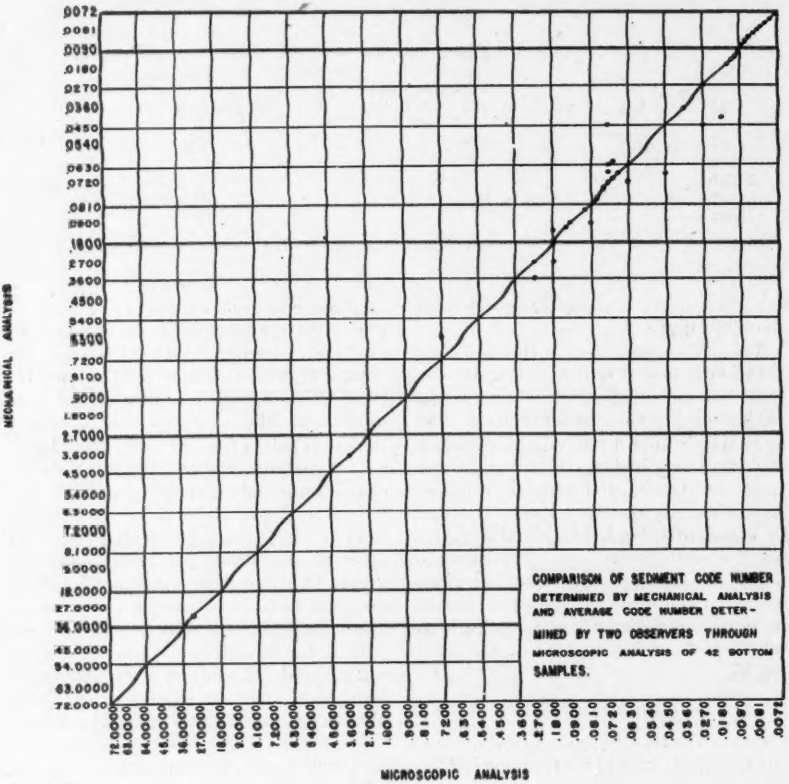
MECHANICAL ANALYSIS
MICROSCOPIC ANALYSIS
COMPARISON OF SEDIMENT CODE NUMBER DETERMINED BY MECHANICAL ANALYSIS AND AVERAGE CODE NUMBER DETERMINED BY TWO OBSERVERS THROUGH MICROSCOPIC ANALYSIS OF 42 BOTTOM SAMPLES.

FIG. 1

curve low on its side or near its peak. Poorly sorted samples may contain grains of such varied sizes that a multidigit code number may be required (*1242*). Some poorly sorted samples may have almost, but not quite, ten per cent of the total grain weight in each of several size grades. Since these small groups can be assigned only a 0 code number, the digits of the complete code number of such samples may total less than nine (*0340*). Thus, the code numbers of the samples indicates the relative degree of sorting, and usually much closer than the standard coefficient of sorting, $So=\sqrt{Q3/Q1}$, because the latter is based only on two points of the cumulative curve: e.g., the quartile measures. For comparison purposes both the code number and the coefficient of sorting were worked out for a large number of sieved and pipetted samples. The results, expressed in Table II, show an increase in the coefficient of sorting with an increasing number of digits in the code number. The sorting coefficient is also higher for samples having code numbers the sum of whose digits is less than nine. Note that most of the samples analyzed would be classified as well-sorted because the coefficient of sorting is less than 2.5 (Trask, 1932). Only 2 of the 388 samples mechanically analyzed would be classified as poorly sorted by Trask's criteria, having a coefficient of sorting higher than 4.5.

TABLE II. *Average coefficient of sorting for various code numbers*

Sum of digits in code number	Number of digits in code numbers 1	2	3	4	5
9	1.20 (25)	1.42 (125)	2.02 (26)	*2.38 (2)*	
8	1.38 (32)	1.55 (100)	2.07 (34)	2.89 (8)	*4.06 (3)*
7	*1.27 (1)*	*1.54 (6)*	*2.63 (5)*	*3.96 (1)*	*1.81 (2)*
6		*1.86 (2)*	*2.34 (1)*		*2.52 (1)*

(Parentheses indicate number of samples on which average is based. The averages italicized are based on too few samples to be significant.)

MEDIAN DIAMETER

For many purposes it is desirable to express the results of size analysis by a single number, the median diameter. The theoretical average median diameter for each code number was worked out but the results were not entirely free from objections, so an empirical method was used. Figure 2 shows median diameter plotted against code number for all samples sieved and pipetted to date. Median diameter was measured from cumulative curves plotted on probability paper; code number was determined from the weight of the size fractions. About half of the analyses could be represented by code numbers of one digit or two digits having a sum of nine. Because many mechanical analyses were purposely made on the less well sorted samples, the remaining half of the code numbers contain three or four digits, or the sum of the digits is only seven or eight. These samples do not fit the ordinate scale of Figure 2, where only code numbers of one or two significant digits are shown. To plot them the two digit number code most nearly corresponding (from the standpoint of median diameter) to the code of the less well sorted sample was used for plotting purposes. For example, a sample with the code *1710* was plotted on the *0900* line, since both samples obviously have a median diameter in the fine sand grade. Similarly, *0800* and *2520* would also be plotted on the *0900* line. The use of less well sorted samples involves some uncertainty, therefore those data are plotted on Figure 2 as open circles in contrast to the solid dots of the well sorted samples. This graph shows that 95% of the points lie within one-half a phi unit to a best fit

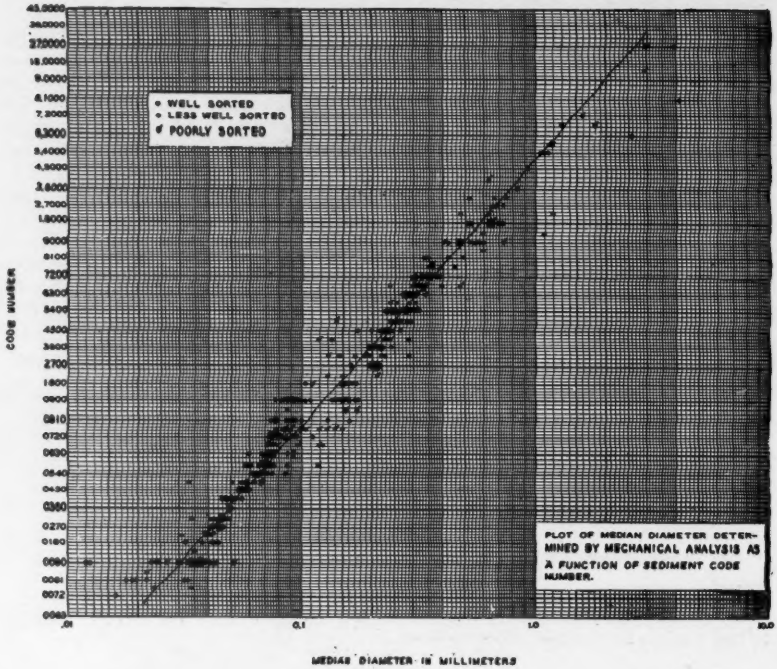
• WELL SORTED
• LESS WELL SORTED
• POORLY SORTED
PLOT OF MEDIAN DIAMETER DETERMINED BY MECHANICAL ANALYSIS AS A FUNCTION OF SEDIMENT CODE NUMBER.
CODE NUMBER
MEDIAN DIAMETER IN MILLIMETERS

FIG. 2

straight line. The variation probably results from the fact that each code number covers an appreciable range in size distribution—for example, the code *0450* applies to a sample which is nearly coarse enough to be coded *0540* as well as to another nearly fine enough to be coded *0360*. Nevertheless, Figure 2 shows that a reasonable estimate of the median diameter can be made from the code number of a sample, through use of the best-fit straight line of the graph.

SKEWNESS

Another parameter useful in sedimentation is skewness, a number which indicates whether the median is on the fine or the coarse side of the mode. From measurements of $Sk = (Q_1Q_3)/M^2$ on mechanically analyzed samples, it is evident that sediments containing one or two adjacent digits have a skewness value which does not differ significantly from unity. For these samples the median and the mode are of practically identical grain diameter. For most of the less well sorted samples, having code numbers of three or more digits, the skewness is obvious. For example, the median diameter is finer than the mode for the asymetrical notation *5210*.

CONCLUSIONS

A method of coding, which expresses the approximate weight frequency distribution of the various size grades in sediment samples, was used in conjunction with a standardized microscopic analysis technique to facilitate analyzing large suites of samples and plotting the

results on charts. The method proved satisfactory for well sorted marine sediment samples. Its value in studying other types of samples is unknown, but it is presented here for possible adaption to other sediments by interested workers.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 1, PP. 24–29
PLATES 1–2, APRIL, 1948

VOLCANIC GLASS, ALLANITE AND ZIRCON AS CHARACTERISTIC MINERALS OF THE TOBA RHYOLITE AT SUMATRA'S EAST COAST

H. W. VAN DER MAREL
Wageningen, Holland

ABSTRACT

Zircon and acidic volcanic glass present in the Toba rhyolitic tuff on Sumatra's East Coast are characterized by a typical habit. Allanite, a mineral usually not occurring in acid volcanic material, is also present.

It is shown that allanite and zircon are concentrated in strongly weathered soils in such quantities that the total of the "heavy" minerals (specific gravity >2.9) consist almost entirely of these two minerals.

INTRODUCTION

Comparatively, the Toba eruption is of a much higher class = ±1500 km³ (Van Bemmelen, Scrivenon) than those of Tambora (Soembawa) = ±150 km³ Cosequina (Mexico) = ±50 km³, Krakatoa = ±18 km³.

The rhyolitic tuff which fell at Sumatra's East Coast from the Toba eruption was afterwards partly covered by dacitic and andesitic material from the younger Sibajak and Sinaboung volcanoes (Druif) and only at some localities of small area do the underlying formations of Tertiary slate and sandstones and soils derived of these rocks appear at the surface.

The rhyolitic tuff contains the following minerals:

"light" fraction (s.g. <2.89):

quartz, sanidine, volcanic glass, biotite (weathered).

"heavy" fraction (s.g. >2.89):

amphibole, hypersthene, allanite, zircon, biotite (unweathered).

Only volcanic glass, allanite and zircon are considered, as only these have been proved to be characteristic for the Toba rhyolite (see Table I).

Properties of volcanic glass, allanite and zircon.

A. CONSTANTS.

(See Table I)

TABLE I

Description	Volcanic Glass	Allanite	Zircon
System	amorph	monoclinic	tetragonal
Cleavage	bad	poor	bad
Fracture	splintery	irregular	conchoidal
Spec. gravity	<2. 89	>2. 89	>2. 89
Color	grayish	brown-black	colorless
Refractive index	n = 1.54	$\alpha = 1.73$ $\beta = 1.74$ $\gamma = 1.75$	$\epsilon = 1.99$ $\omega = 1.94$
Birefringence	none	moderate	strong
Optical axes	isotropic	biaxial negative	uniaxial positive
Pleochroism	none	strong (from brown to dark red brown)	very weak

B. CHARACTERISTICS IN SEDIMENTS.

Volcanic glass.

The volcanic glass is "acidic" and its angular splintery sides and contained air bubbles (fig. 1) are very typical. This glass is very resistant to weathering so that it is still present in soils which are maturely weathered.

Other formations on Sumatra's East Coast also contain volcanic glass (fig. 2) but the particles have different shape and are "basic." Moreover, the "basic" volcanic glasses from dacitic and andesitic lavas easily decompose, so that they usually are absent in maturely weathered soils.

Allanite.[1]

According to the cited literature, allanite occurs in metamorphic rocks and igneous rocks of more acid origin.

That allanite is found in the acid effusive Toba rhyolitic tuff is important. In the fresh rhyolitic tuff it occurs in the form of monoclinic prisms (figs. 3 and 4). Weathering forms teeth (fig. 5) over all of a particle (fig. 6) and the directions of the teeth do not always agree with the direction of cleavage of this mineral.

According to Edelman, even particles of minerals with perfect cleavage, such as pyroxene and amphibole, are covered with teeth by weathering. Furthermore, by weathering, sharp angular holes are formed, caused by loss of crystal inclusions (fig. 7). In the final stages of weathering, allanite assumes a ragged shape (fig. 8).

Zircon.

The zircon in the rhyolitic tuff contains typical inclusions of small crystals, needles and gas bubbles (fig. 9 and 10). This is not the case with the zircon in other formations on Sumatra's East Coast, but is like the zircon present in the alluvial soils of Sumatra's West Coast (fig. 11).

Zircons in rounded particles (caused by mechanical weathering) and with air bubbles are present in formations of Tertiary age on Sumatra's East Coast (fig. 12).

As zircon is very resistant to weathering, its original shape is long kept and thus in deeply weathered rhyolitic soils where allanite appears in ragged forms, zircon is still present in prisms (figs. 13 and 14).

Method of analysis (Edelman).

±20 grams of the soil are boiled with 40 cc of 30% hydrogen peroxide and 10 cc of 10% acetic acid until all peroxide is decomposed. After that the soil is passed over a sieve of 50μ using water while rubbing. The fraction retained on the sieve is treated with strong hydrochloric acid if the minerals are covered by sesquihydroxides (oxides) and it is sieved once again. The material thus obtained is dried at 105° c. and passed over a sieve of 250μ. Then the fraction 50 – 250μ is separated by means of bromofrom with a specific gravity of 2.89 into a "light" and a "heavy" fraction. Each fraction is mounted on a slide in Canada balsam. The minerals are then identified and counted by moving the slide mounted in a micrometer stage.

Results.

"LIGHT" FRACTION (s.g. <2.89)

The "acidic" volcanic glass of the rhyolitic tuff is characteristic for this formation, but it does not occur in soils which are strongly weathered. As the "basic" volcanic glasses of dacitic and andesitic origin on Sumatra's East Coast are easily decomposed by weathering, the "light" fraction is not suited for identification of the several formations present at Sumatra's East Coast.

"HEAVY" FRACTION (specific gravity >2.89).

Because characteristic "guide" min-

[1] Possible sources of allanite as mentioned by authors: Kraus—granite, pegmatite, gneiss, mica, amphibole schist, limestone. Milner—acid igneous rocks, metamorphic rocks, certain iron ores. Steinrede—granite, syenite, diorite. Weisbach—granite, syenite, trachyte, gneiss, limestone.

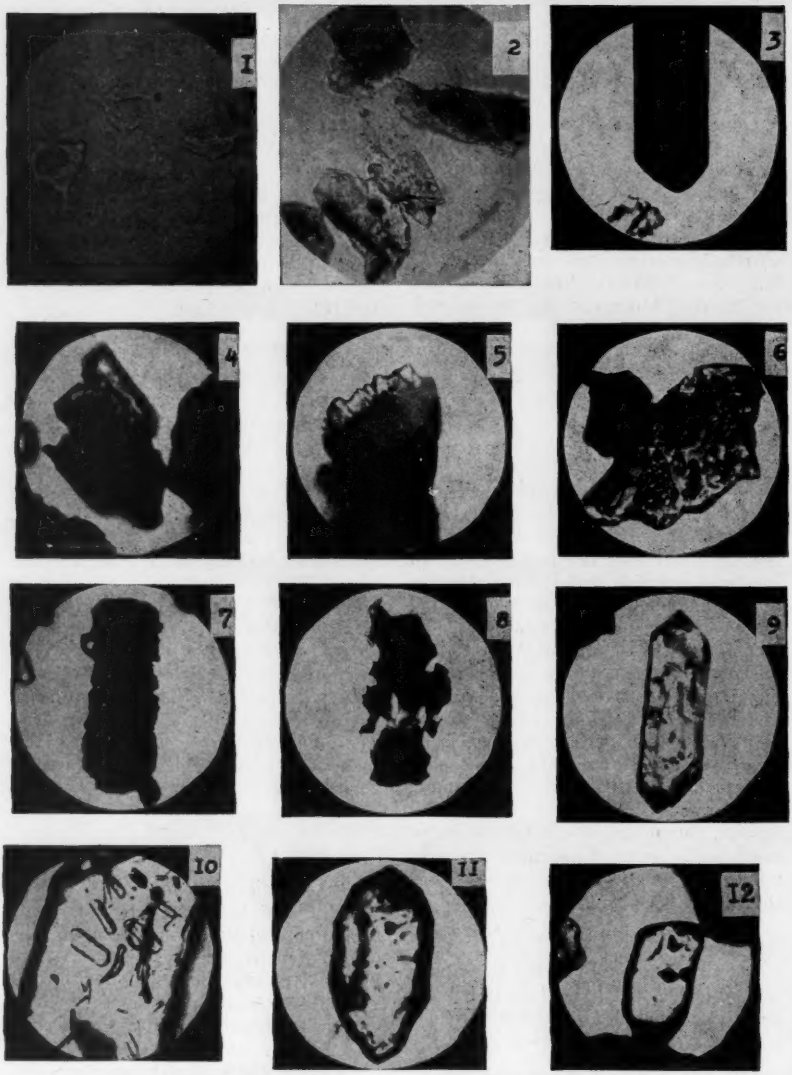

PLATE 1
(*Explanation on facing page*)

erals are present, the "heavy" fraction of the several formations on Sumatra's East Coast may be used to identify the individual formation.

Moreover, it proved to be possible to use the "heavy" fraction to identify the stage of weathering of the rhyolitic soils, as the minerals allanite and zircon are difficulty decomposed and become concentrated as the soil is weathered. The degree of concentration is thus some measure of the extent of weathering. This is shown in Table II.

The figures are averages of 10 soils belonging to the same stage of weathering according to their agricultural value.

From the above, it may be concluded that the very strongly weathered soils of Sumatra's East Coast that are the so-called "yellow" semisubhydrical rhyolitic soils, consist largely of the very resistant allanite and zircon (fig. 13). The same is shown by rhyolitic tuff which is attacked by strong acids from fumaroles (fig. 14).

In the "yellow" soils many manganese-

TABLE II

a) Soils derived from rhyolitic, dacitic, andesitic and metamorphic rocks.

Soil derived from	*Guide minerals*
Rhyolitic rock	allanite and zircon
Dacitic rock	hypersthene with absence of allanite and rhyolitic zircon
Andesitic rock	as dacitic rock, but with more hypersthene
Metamorphic rock	tourmaline, garnet, rutile and rounded zircon of pink color

b) Soils derived of rhyolitic rocks.

Stage of weathering	Ore and opaque	Hyper-thene	Amphi-bole	Alla-nite	Zircon
	%	%	%	%	%
Rhyolitic tuff, unweathered	43	5	42	4	6
Slightly weathered soil	53	2	32	5	8
Moderately weathered soil	62	1	14	10	13
Strongly weathered soil	36	traces	5	28	31
Very strongly weathered soil	20	absent	absent	40	40

EXPLANATION OF PLATE 1

Description of figures (diameter of the minerals = 50μ to 250μ).

1. Volcanic glass, from rhyolitic soil.
2. Idem. from andesitic soil.
3. Allanite with predominant column-structure, from rhyolitic soil.
4. Allanite more weathered, from rhyolitic soil.
5. Allanite with predominant teeth-structure, caused by weathering, from rhyolitic soil.
6. Allanite with teeth-structure all over the particle, from rhyolitic soil.
7. Allanite with sharp angular holes, caused by loss of crystal inclusions by weathering, from rhyolitic soil.
8. Allanite strongly weathered, from rhyolitic soil.
9. Zircon with predominant column-structure and inclusions, from rhyolitic soil.
10. Zircon with inclusions (gas and crystals), from rhyolitic soil.
11. Zircon with inclusions, from alluvial soils at Atjeh (N. W. Coast of Sumatra).
12. Zircon with rounded edges and holes with air, from soils (slates and sandstones) of Tertiary age on Sumatra's East Coast.

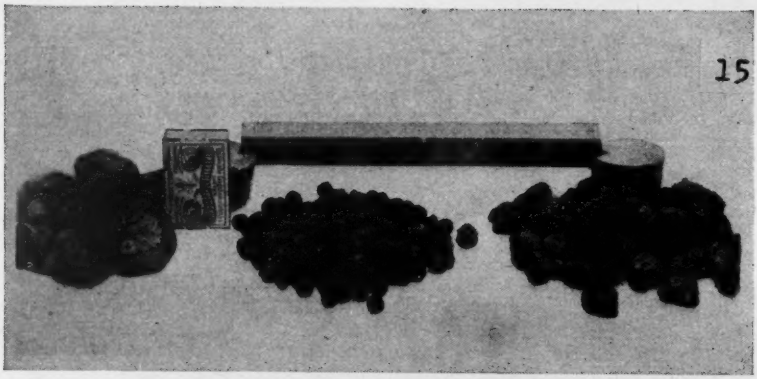

PLATE 2
(Explanation on facing page)

iron concretions are found ($Fe_2O_3 = \pm 19\%$, $Al_2O_3 + TiO_2 = \pm 15\%$, $Mn_3O_4 = \pm 18\%$) which sometimes become several centimeters in diameter (fig. 15). Moreover, in these "yellow" soils vast banks (fig. 16) of manganese-iron may be present ($Mn_3O_4 = \pm 8\%$). These resulted from the cementation of the soil by means of the manganese and iron.

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EXPLANATION OF PLATE 2

13. "Heavy" mineral fraction (s.g. > 2. 9), from strongly weathered so-called "yellow" rhyolitic soil; zircon (z) with inclusions, allanite (o) weathered with characteristic structure. The other minerals are ore.
14. "Heavy" mineral fraction, from rhyolitic tuff weathered by fumarole action.
15. Concretions of manganese-iron in rhyolitic soil.
16. Pan of manganese iron just below the surface in rhyolitic soil.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 1, PP. 30–33
PLATES 1–2, APRIL, 1948

UNDERWAY BOTTOM SAMPLER[1]

K. O. EMERY
University of Southern California, Los Angeles, California
AND
A. R. CHAMPION
Scripps Institution of Oceanography of the University of California, La Jolla, California

ABSTRACT

A new instrument for collecting bottom samples was designed for operation from aboard ships moving at speeds up to about ten knots. Use of this sampler permits accurate correlation of bottom materials with bottom topography because both the sampler and a recording (echo-sounder) can be operated simultaneously.

Most instruments for collecting samples from the sea floor are designed to be lowered as near vertically through the water as possible and depend upon the impact of striking bottom or the release of cable strain to activate a closing mechanism to keep the sample from washing out as the instrument is hoisted back to the surface. Clam-shell snappers, orange-peel buckets, rotating drum scoops, coring devices, and most dredges thus require the sampling ship to heave-to or at least to move only slowly through the water. Because quite a lot of time is required to stop the ship and then to start it moving again to the next sampling position, only a limited number of bottom samples can be obtained during a working day.

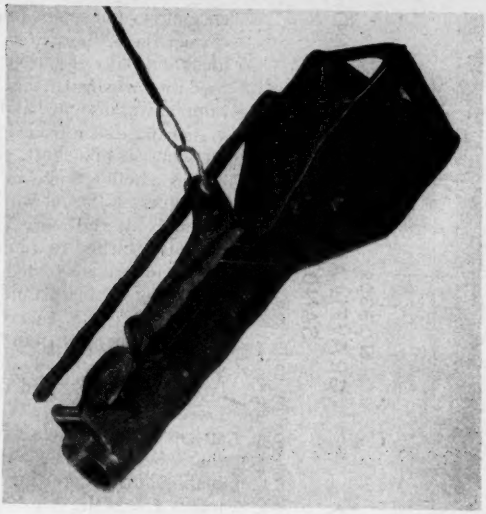
Early in the recent war an instrument called the bathythermograph was developed at Woods Hole Oceanographic Institution for obtaining a continuous curve of water temperature plotted against depth. It was lowered from ships moving through the water at speeds up to about fifteen knots. This was made possible by the use of a winch capable of paying out light cable behind the ship at a rate faster than the forward speed of the ship. The instrument has a heavy nose to facilitate rapid sinking through the water and tail fins to provide control as it is hauled back up through the water to the ship. After the bathythermograph had touched bottom several times in water less than about 70 fathoms deep, a small tube was attached to the nose to collect a bottom sample on the same cast that a temperature-depth curve was obtained. Finally, a device for bottom sampling alone was developed, again at Woods Hole Oceanographic Institution (Ewing, Woollard, Vine, and Worzel, 1946; Worzel, 1947). Samplers of this design were used with good success on both the Atlantic and Pacific coasts; however, continued use showed the pres-

[1] This paper is based on data obtained by the University of California Division of War Research under Bureau of Ships Contract Nobs-2074 (formerly OEMsr-30).

EXPLANATION OF PLATE 1

PLATE 1. (A) Underway sampler in cocked position before it strikes bottom. Note that the towing point on the hinged arm is aft of the center of gravity, that the hinged door is open, and that the sampling cup protrudes. Photo by U. S. Navy Electronics Laboratory.

(B) Underway sampler in sprung position, as in retrieving. Note that the released hinged towing arm permits towing from a forward position and that the sampling cup has been pushed inside and is covered by the closed door. Photo by U. S. Navy Electronics Laboratory.



A

B

PLATE 1

(Explanation on facing page)

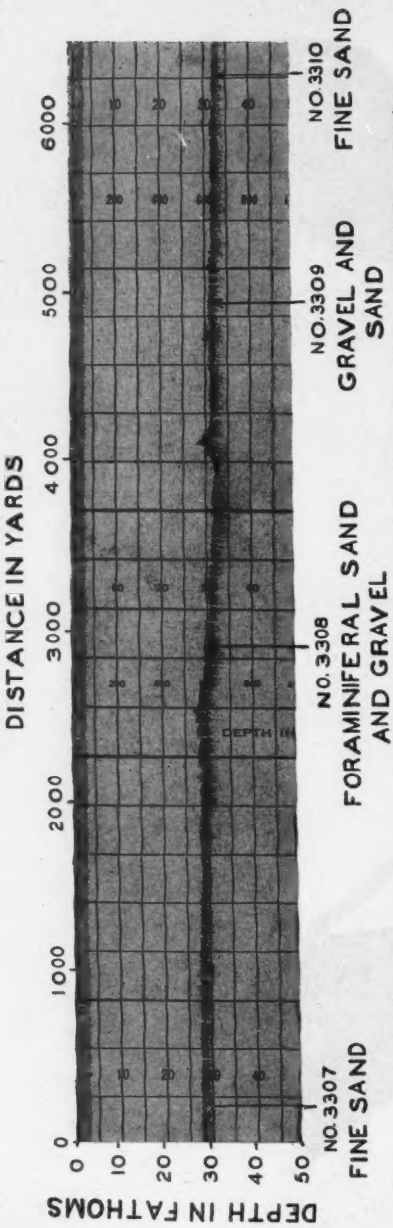


PLATE 2. Recording echo-sounder trace with notations of bottom materials collected by underway sampler. Note that low flat areas consist of fine sediment while irregular hills are of rock surrounded by gravel.

ence of several minor faults. In order to correct these, the writers combined their ideas and those of various others who had used the early instrument, and the present sampler was designed and built.

As can be seen from Plate 1, the sampler consists of a short, nearly solid body having a hollow barrel in which is located a sampler at the forward end and a tail assembly at the rear. The light towing cable is attached to a hinged arm, which during lowering is folded back so that the tow point is about amidships of the instrument. When cocked for sampling the cup protrudes from the barrel about one centimeter and at this position latches open a hinged door against the pressure of a spring. When the sampler strikes bottom the cup is driven back into the barrel, releasing the door, which snaps shut to prevent washing of the trapped sample. During this action a catch is sprung, freeing the after end of the hinged towing arm so that during hoisting the tow point is nearer the forward end of the sampler. This permits the sampler to be retrieved with a minimum of drag, and prevents it from spinning end-over-end when it is hoisted from the water. A negligible amount of maintenance is required, owing to construction from stainless steel, together with the dashpot cushioning effect inherent in the cup action.

In operation, the sampler is slowly lowered overside while the ship is underway. As soon as it strikes the water, the winch brake is released so that cable pays out very freely and rapidly. Contact with bottom is indicated by a slight slackening of the cable, and the winch is stopped immediately. The sampler then is hoisted back to the surface and aboard ship.

About four thousand bottom samples have been obtained with this sampler and with an earlier version having a fixed towing point, between depths of a few to about one hundred fathoms. These samples came from bottoms of mud, sand gravel, rock, and coral. Samples of mud or sand usually are thirty to fifty grams in weight, enough for most types of sedi-

mentary analysis. Most rock and coral samples are smaller and consist of only a few chips but these may be sufficient for identifications. No serious damage has ever resulted from the striking of rock bottom and no sampler has yet been lost. In the collection of bottom samples misses are inevitable, but for the underway sampler the misses are surprisingly low; less than ten per cent for the four thousand samples obtained so far. These misses result from various causes such as the striking of bare hard rock bottom, reeling in of cable before bottom is reached, and failure to make proper readjustments as wear of sampler parts takes place. The time required for sampling is as short as two minutes per sample in water of thirty fathoms depth. Nearly two hundred samples have been collected during a single day.

In addition to making possible the collection of large numbers of samples per unit time, the underway sampler permits the accurate correlation of bottom materials and bottom topography, because continuous sampling can be carried on simultaneously with the making of a recording echo-sounder trace. After the samples have been examined, their character can be entered at the proper time intervals on the sounding record as shown by Plate. 2. Many such comparisons have been made and they show the consistent presence of coarse sediment on topographic high spots and finer sediment on surrounding flat areas. It is believed that correlated use of the underway bottom sampler and the recording echo-sounder traces will prove to be a very valuable tool in the understanding of contemporary sedimentation.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 1, PP. 34–37
FIGS. 1–2, APRIL, 1948

NEW SNAPPER-TYPE SEA FLOOR SEDIMENT SAMPLER

E. C. LAFOND AND R. S. DIETZ
U. S. Navy Electronics Laboratory, San Diego 52, California

ABSTRACT

A new snapper-type bottom sediment sampler is described. The spring- and weight-loaded jaws are closed around a bottom sample upon striking the sea floor by a foot trip. Field use has shown that this new device gives better performance than other similar samplers.

In connection with the U. S. Navy oceanographic research program it is necessary to obtain numerous bottom sediment samples. In their present work in the Oceanographic Section of the U. S. Navy Electronics Laboratory and in previous work at the University of California Division of War Research and at the Scripps Institution of Oceanography, the writers have used many kinds of snapper-type bottom samplers but have not been satisfied with the performance of any of those used. Therefore, a new snapper sampler was recently developed and tested at the Navy Electronics Laboratory, and this has proved more satisfactory than any other similar device known to the writers.

Briefly, the snapper consists of a pair of spring-loaded jaws, a foot-type trigger, a shaft, and a 16-pound lead weight which also tends to close the jaws when the device is in an upright position. The device has a total weight of 41 pounds and an over-all length of 29 inches. All parts are of rugged construction and made of corrosion resistant material, mainly stainless steel. The general appearance of the snapper is shown in Figure 1. Some details of construction are shown in Figure 2.

This new snapper is based on a snapper developed at the University of California Division of War Research in connection with sea floor studies by F. P. Shepard, K. O. Emery, and others. This was modified by substituting the foot-tripping device for the slack-wire release and by addition of the closing spring which maintains tension on the jaws at all times. Also, the design has been simplified and the device made considerably more rugged.

In the first model, a set of four fins was welded to the top of the shaft to insure vertical descent and, especially, to reduce to a minimum the tendency of the sampler to spin. However, the fins are now considered unnecessary and have been eliminated from the more recent model.

The two jaws are cast of a nickel-iron alloy for toughness and are machined to a tight fit to prevent washing of the sample. The jaws have an interior bevel to reduce the area of mutual contact. This gives the jaws a stronger bite and also reduces the chance of the jaws being wedged open by coarse fragments. Such wedging of the jaws is an inherent defect of all snappers and occasionally results in the loss of most of a sample.

The jaws are partially activated by a stainless steel spring around the one inch stainless steel central shaft. The coil spring has an outside diameter of 1–5/16 inches and is composed of 70 turns of 1/8 inch wire, making a coil approximately 22 inches long when under no compression. A protective shield over the spring prevents fouling or damage on rocks. The spring is used (1) to maintain a constant tension on the jaws to prevent tripping when the lead weight becomes jerked by the winch or the roll of the ship and (2) to close the jaws when the snapper is tripped on striking the bottom, even

when an excess of wire is payed out allowing the snapper to fall on its side. In this position the lead weight does not maintain a tension on the jaws.

The lead weight is connected by arms to the sides of the jaws. When the snapper is in an upright position the weight tends to close the jaws. The lead weight also keeps the snapper properly oriented when falling free through the water and it furnishes the driving force on striking the bottom. On retrieving, when the wire is tight, the weight helps, together with the spring, to keep the jaws tightly closed.

The foot-type trigger consists of a slotted bar which fits over a pin. A foot on the end of the bar extends just below the jaws so that upon striking the bottom the bar slides up off the pin allowing the jaws to close. The foot is designed so that it requires a force of about nine pounds to trigger the snapper. Falling through the water slightly reduces the required force for tripping so that the device has invariably closed even on soft silt bottoms.

As used at the Navy Electronics Laboratory, the snapper is lowered to the bottom from a winch using wire rope usually 3/32, 1/8, or 5/32 of an inch in diameter and of 7×7 or 7×19 strand construction. Upon striking the bottom, the foot trigger is pushed off a pin which permits the jaws to close around a sample

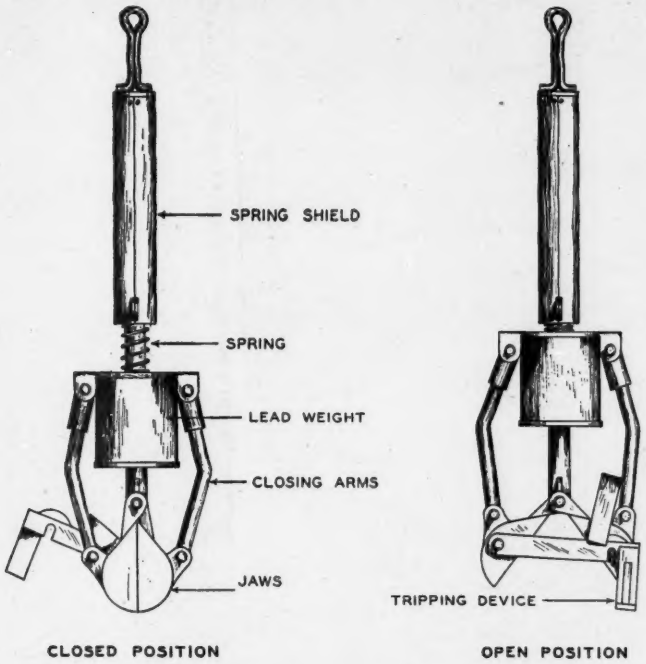

FIG. 1. Sea floor sediment snapper shown with the jaws in a closed position as when retrieving and with jaws in an open position as when lowering.

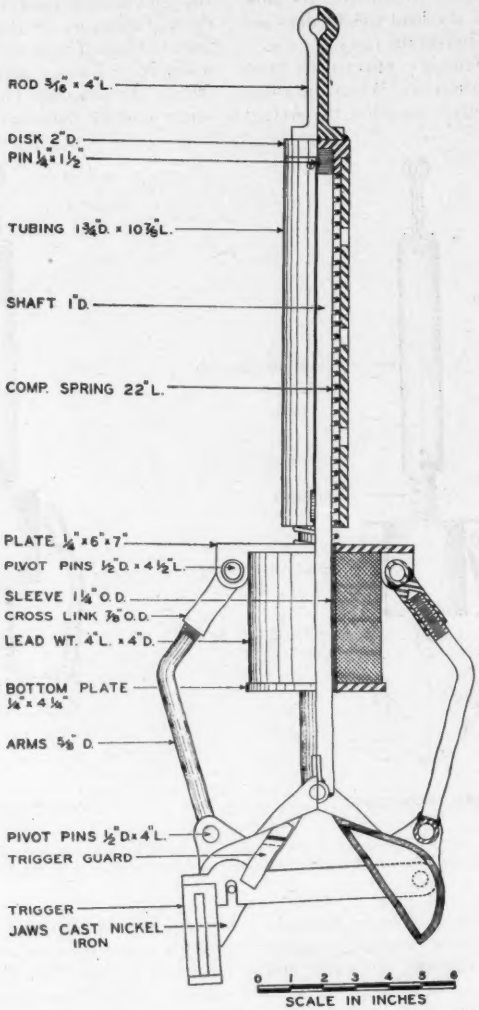
ROD 5/16" x 4"L.
DISK 2"D.
PIN 1/4" x 1 1/2"
TUBING 1 3/4"D. x 10 7/8"L.
SHAFT 1"D.
COMP. SPRING 22"L.
PLATE 1/4" x 6" x 7"
PIVOT PINS 1/2"D. x 4 1/2"L.
SLEEVE 1 1/4" O.D.
CROSS LINK 3/8" O.D.
LEAD WT. 4"L. x 4"D.
BOTTOM PLATE 1/4" x 4 1/8"
ARMS 5/8" D.
PIVOT PINS 1/2"D x 4"L.
TRIGGER GUARD
TRIGGER
JAWS CAST NICKEL IRON
0 1 2 3 4 5 6
SCALE IN INCHES

FIG. 2. Some details of construction of the sea floor sediment snapper.

of sediment. In shoal or intermediate depths striking the bottom is indicated to the operator aboard ship by slacking of the wire. As the weight of the sampler is small as compared to the weight of the wire at great depths, it is advisable to strap an additional lead weight to the shaft of the snapper when using it in very deep water. After retrieving the sampler, the sample may be readily removed and the device once again cocked by inverting it. In this position, the 16-pound lead weight slightly more than balances the force of the spring so that the jaws open up.

The snapper has been tested and found to operate effectively in work off the southern California coast, in sampling of the bottom during two trips to the Arctic, in work off Hawaii, and in obtaining sediment samples at Bikini in connection with the 1947 re-survey of that atoll. If soft mud or fine sand bottom is encountered, a full sample of about one pint in volume is recovered. If the bottom is composed of coarser material, the snapper is usually only partially filled. Although the device is not designed to recover rock samples, fragments are some times recovered from rock bottom. More often, encrusting substances such as algae, bryazoa, and other organisms are obtained. In the Arctic, a smelt-like fish was caught at one station and a small halibut was caught at another. The efficiency of the snapper in picking up material is frequently demonstrated in the laboratory by picking up small grains, pins, and postage stamps stuck to a cement floor.

The chief advantage of this new snapper over certain previously used types is in the simple and effective triggering mechanism which insures closing of the snapper upon striking the bottom and which prevents premature tripping even if the winch is suddenly stopped or the wire violently jiggled. Also, the sampler may be lowered at its terminal free-fall velocity in water without danger of premature tripping such as would result if the device utilized a trigger released by slacking of the wire. Other advantages include the simplicity and ruggedness of construction, the ease of cocking, resistance to corrosion, and the tight fit of the jaws which prevents washing of the sample. The device is sufficiently light to be readily handled aboard a vessel and to be lowered on small wire (3/32 of an inch); yet, it is sufficiently heavy so that striking the bottom is clearly indicated by slacking of the wire in shoal and moderate depths. The large-size sample usually obtained is sufficient for most work on bottom sediments. Small rock fragments or encrusting substances are often recovered even from rock surfaces.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 1, PP. 38–42
APRIL, 1948

WEATHERING AND HEAVY MINERALS

VICTOR T. ALLEN
Saint Louis University, St. Louis, Missouri

ABSTRACT

Weathering destroys some heavy minerals at the source so they are not represented in the resulting sediments. Stable minerals are concentrated by weathering and their proportion in the resulting sediments is greatly increased.

Exact information on the variety of garnet, hornblende or other members of variable groups should be given whenever possible, because all varieties of these minerals do not offer the same resistance to weathering. Discrepancies in statements regarding the stability of these minerals during weathering will disappear when more exact data on the composition of the mineral variety are available.

INTRODUCTION

In a recent paper in this journal (Dryden and Dryden, 1946) the interesting problem of the destruction of some heavy minerals and of the concentration of others in the source rocks and the effects of this process on the resulting sediments are discussed. The authors of this paper state "there are very few published data on this aspect of the problem of non-appearance of available heavy minerals." They express the hope that their paper will direct attention to "this neglected phase of heavy mineral studies." Also, they re-open the disputed question of why garnets are absent from certain sediments and contribute new observations regarding the weathering of garnetiferous crystalline rocks of Pennsylvania and Maryland.

Results of several studies by the writer that contribute to this problem are summarized here for those interested.

IONE FORMATION

The Ione formation lies along the foothills of the Sierra Nevada Mountains in the Great Valley of California. It consists of quartz sands and gravels, clays and seams of lignites that were deposited as deltas by Eocene streams which also deposited the prevolcanic auriferous gravels on the higher slopes of the Sierra Nevada Mountains. It is composed of quartz, anauxite, zircon, tourmaline, ilmenite, epidote, andalusite, sillimanite, rutile and rarely a few grains of green hornblende and garnet. (Allen, 375–377, 1929.) This mineral assemblage contrasts with that in the underlying Cretaceous sandstones, in which feldspars, biotite, and hornblende are abundant; and garnet, titanite and other minerals are well represented. The presence of detrital andalusite in the Ione sediments and its occurrence as a contact mineral produced by the granitic intrusions in the Mariposa slates (Turner 1896; Lindgren 1896; 1897.) and additional evidence suggest that the source of the Ione sediments was the Sierra Nevada bedrock complex. However, the granitic rocks which occupy large areas in the Sierra Nevada complex also contain abundant feldspar, biotite, hornblende, and minor accessory minerals not found in the Ione formation. These minerals must have been removed by chemical weathering, if the Ione mineral assemblage was derived from this source.

The bedrock at the Manzanita Hydraulic Mine near Nevada City in the Colfax quadrangle is a biotite-hornblende granodiorite with titanite, zircon and magnetite as minor accessory miner-

als. In places below the quartz gravel of Eocene age it is altered to a light-colored residual clay containing angular quartz grains, euhedral zircon, anauxite, and other clay minerals that were derived from feldspars, biotite, and hornblende; pellets of red iron oxide were derived from magnetite and brown clay formed from titanite (Allen, 387–388, 1939). Quartz and zircon were the only minerals in this rock that remained unaltered. Therefore, the conclusion was reached that the Ione assemblage is characterized by minerals which are resistant to chemical decay and that chemical weathering under the tropical climate of the Eocene removed perishable minerals at the source and prepared the minerals that were later deposited as the sediments of the Ione formation.

GLACIAL DEPOSITS IN ILLINOIS

A petrographic study of the weathered zones of glacial deposits, which was carried on under the auspices of the Illinois State Geological Survey, showed that feldspars and heavy minerals were destroyed in the upper part of the profiles of weathering (Allen, 1930 and 1932). Weighed heavy mineral separations from weighed samples of Kansan, Illinoian, and Wisconsin drift were examined and showed a one- to five-fold decrease in amount of heavy minerals towards the top of the profile. Photomicrographs recorded hornblende and epidote in the upper zones partly altered to clay minerals at the edges and along cleavage. Magnetite was oxidized to red iron oxides. Apatite and other easily altered minerals were completely absent from the upper zones but were sparsely represented in the unleached zones. No notable decrease in amounts or in freshness of garnet and kyanite grains was observed towards the top of the profile.

UNDERCLAYS OF ILLINOIS COAL

The methods employed in the study of the weathered zones of glacial deposits were extended to the underclays of Illinois coal (Allen 1932). The degree of weathering of the underclay since its deposition was compared with that shown on the Kansan, Illinoian and Wisconsin drift. The presence of biotite, hornblende, epidote, and fresh feldspars within one to seven inches below the coal suggested that weathering after the deposition of the underclays has been slight, more like that on the Wisconsin till than that on the Kansan or the Illinoian. Some of the photomicrographs compared features of the weathering of glacial deposits with those of the underclays.

LOESS NEAR ST. CHARLES, MISSOURI

Oefelein (1934) studied the loess deposits near St. Charles, Missouri, under the direction of the writer. Her observations indicate that the percentage of heavy minerals decreases towards the top of the deposit, that the ferromagnesian minerals show little evidence of alteration, and that garnet, zircon and tourmaline remain nearly constant from bottom to top while hornblende appears to decrease somewhat towards the top.

CERAMIC CLAY IN HAWAII

The unusual feature of this clay is its content of 14 to 15 percent titania (Wentworth, Wells and Allen 1940), which is present as ilmenite and leucoxene. It was apparently derived from the basaltic lavas of the island, which range in titania from 1.48 to 4.05 percent. Concentration of titania along with alumina during chemical weathering is an established process. But, since this clay contained only 25 percent alumina, it was considered that a mechanical concentration of ilmenite was necessary to bring about a fourfold increase over that present in the parent rock.

CONCENTRATION OF ILMENITE IN CLAYS, SANDS AND GRAVELS

Investigation of high-alumina clay by the U. S. Geological Survey revealed additional information on the concentration of ilmenite in residual clays derived from basaltic lavas of the Columbia River Region (Allen and Nichols 1946). Laths

of plagioclase are altered to kaolinite-halloysite, but retain their shape and along with plates of ilmenite give to the weathered rocks an appearance suggesting that the original texture of the basalt has been retained. This is true to a certain extent and it is accomplished in this manner. The glassy groundmass and the ferromagnesian minerals alter first to nontronite, but the plagioclase laths and ilmenite plates remain unaltered (Allen and Scheid, 1946). With the removal of certain ions in solution and the migration of nontronite from the groundmass, the firm plagioclase laths and ilmenite plates change their positions but retain their shapes as compaction takes place. Later when the laths change to kaolinite-halloysite further adjustment is possible and necessary. Typical basalts of the Columbia River Region average about 1.7 percent TiO_2 and the average residual clay derived from basalt of the Excelsior deposit averages over 7 percent TiO_2. It would require more than a fourfold concentration of TiO_2 to account for the TiO_2 in these clays.

DETRITAL GARNET PROBLEM

Statements regarding the occurrence of garnets in sedimentary rocks vary widely. Condit (1912) reported the absence of garnet in the sandstones of Ohio, Africa, Arabia and Britain. He regarded it as a stable mineral and believed its absence or scarcity in early Paleozoic sandstones suggested a derivation from sources lacking abundant garnet. Graham (1930) found garnet to be present in the Cambrian sandstones of Minnesota and considered that when garnet occurs in their heavy mineral separates in amounts greater that 90 per cent, it suggests the Jordan formation rather than the other Cambrian formations of Minnesota. Thiel (1935) reported a restricted distribution of garnet in the St. Peter sandstone of Minnesota.

Dryden and Dryden (1946, p. 94) give values for the resistance to weathering of several heavy minerals, in which garnet is taken as 1 and is less resistant than hornblende. They emphasize that the figures apply to the Maryland-Pennsylvania region only.

Milner (1923; Raeburn and Milner 1927) rate garnet as a highly stable mineral and place it with zircon and tourmaline in resistance.

In the Great Valley of California the occurrence of abundant garnet in the Cretaceous formations and the lack or scarcity of garnet in the Ione formation would appear to suggest that weathering in pre-Ione times removed it along with the other perishable minerals (Allen 1929). This would necessitate the assumption that the Cretaceous and Eocene rocks were derived from the same source under different conditions of weathering and sedimentation. At no place was a remnant of the pre-Ione weathered surface found where garnet-bearing fresh rock could be compared with its weathered products, and so test this possibility.

In the weathered zones of glacial deposits in Illinois garnet was not observed to decrease near the top of the profile, but hornblende decreased in amount towards the top of nearly all the weathered zones examined. Also, numerous grains of hornblende were seen with their edges and cleavages coated with alteration products but garnet seemed unaltered. Even if allowance is made for the possibility that the top part of the glacial drift was not identical in mineral composition with the lower zones, these observations suggest that garnet was more resistant to weathering than hornblende was in the glacial deposits of Illinois.

Frank (1944) found garnets in several Pennsylvanian cycles of the St. Louis area, but the amounts are too small and the distribution too irregular to use in connection with this problem.

In the kaolins of North Carolina the writer observed brownish spots caused by the weathering of high-iron garnets. Earlier Bayley (1925) made a similar observation and his statement regarding it is quoted:

"The most objectionable components of the kaolin are the decomposition products of the garnets. When these are decomposed they give rise to chlorite and other micaceous products that are often colored reddish brown by iron hydroxides or other iron compounds. The heaviest particles may be separated from the kaolin in the washing process, but some of the lightest material floats over with the slip and is distributed through the refined kaolin, often impairing its value to a serious degree. In the clay-bank the presence of the decomposed garnets is revealed by the presence of little circular brown spots. When the spots are few the clay containing them may be removed by hand-sorting before the crude material is sent to the washer. Where abundant there is no recourse for the miner but the abandonment of that part of the mine in which they occur."

These observations suggest that the garnets which are easily decomposed by chemical weathering are those high in iron. A statement by Dana (1895) is of interest in this connection:

"Garnets containing ferrous iron often become rusty and disintegrate through the oxidation of iron and are sometimes altered more or less completely to limonite, magnetite or hematite. . . .

The common iron-aluminum garnet is especially liable to alteration."

The apparent contrary statements about garnets being very stable and also very easily altered may be reconciled, if some members of the garnet group are more resistant to chemical weathering than are others. If garnets can be liberated by rapid erosion in advance of their chemical decomposition, they offer strong resistance to abrasion. Their hardness, toughness, and lack of cleavage are the properties that have been the basis of their use as abrasive materials in industry.

Freise (1931) determined that iron garnet has a lower relative resistance to abrasion during transportation than calcium garnet.

Exact information on the variety of garnet and its behavior under specific conditions is needed before further progress in the solution of this problem can be expected. Whenever possible chemical analysis, optical and X-ray data should be recorded because overlapping of optical properties makes it difficult to determine some members of the garnet group from their optical properties alone.

Effort has been made by some investigators to report the kind of garnet present. In the mineralogical and chemical studies of soil formation from acid and basic igneous rocks in Missouri, Humbert and Marshall (1943) state that several species of garnets are sparingly present. The garnet in the soils from granitic rocks shows strong resistance to weathering. In the diabase there are probably lime-iron garnets of the variety melanite and also iron and manganese garnets. Some of these garnets are said to appear somewhat weathered.

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FIG. 1, APRIL, 1948

A SIMPLE VOLUMETER

ROBERT L. MILLER
Department of Geology, University of Chicago, Chicago, Illinois

ABSTRACT

Method of construction and operation of a volumeter is described. This device measures volume by direct reading, and was used in a study of invertebrate fossils and pebbles.

INTRODUCTION

A problem, which called for volume measurements on many individuals of a species of brachiopod, made it necessary to design a reasonably accurate volumeter. The apparatus had to be simple in its operation and require a minimum of calculation.

After the writer had designed and built the apparatus described below, he found that a somewhat similar instrument had been used by H. A. Segar (Beyer and Williams 1903, p. 107). Segar's volumeter, however, differs in some details. Accordingly the author believes a note on the volumeter used by him may prove useful to others who have need for such a device.

THE APPARATUS

The apparatus consists of a glass cylinder of diameter just larger than the largest of the objects to be measured, a 10 c. cm. straight bore pipette graduated along the length into divisions of .1 c. cm. two pieces of rubber tubing, a syringe bulb, and a pinch clamp.

The glass cylinder is open at the top and has a short glass tube on the side just above the closed bottom, so that it can be attached to the bottom of the pipette by a piece of rubber tubing (fig. 1). The constricted part of the pipette is removed to insure the free passage of water from the cylinder to the pipette. Both cylinder and pipette are clamped in an upright position to a stand.

A second piece of rubber tubing is fitted over the top of the pipette. The other end is attached to the syringe bulb by a short piece of glass tubing. The rubber tube just mentioned is long enough so that it can be conveniently held in the hand of the operator while his eye is at a level with the water in the cylinder.

The basic principle involved is that of direct displacement of water for a measure of volume. $V_p + V_o$ equals the volume of water displaced by the object, where

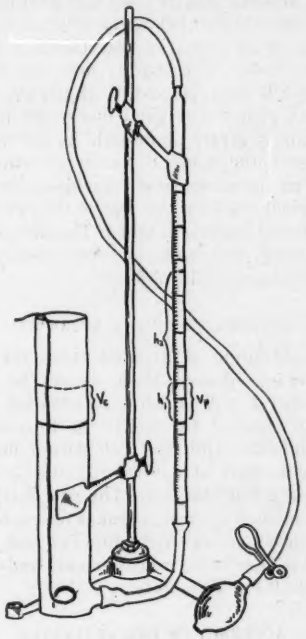

FIG. 1

V_c is the amount of rise in the cylinder and V_p is the corresponding rise in the pipette (fig. 1). In order to measure V_c, it is necessary only to draw the water up into the pipette until the surface of the water has dropped to its original level. Then heights h_1+h_2 will give a direct reading of the volume of the object.

Step 1.—A piece of copper wire looped at one end provides a stage for raising and lowering the object into the cylinder. The wire is lowered until the loop rests on the bottom of the cylinder and the water level is marked by placing a piece of Scotch Tape on the outside of the cylinder. A reading is then taken on the pipette.

Step 2.—The wire is pulled up and the object placed in the loop, and then lowered to the bottom of the cylinder.

Step 3,—By creating a partial vacuum with the syringe bulb, the water is drawn up into the pipette until the level in the cylinder is well below the original mark. The pinch clamp is now fastened onto the rubber tube (fig. 1) near the bulb, which is then released. With the eye at a level with the original mark, the pinch clamp is gently depressed. As the water drops in the pipette it rises in the cylinder. When the water level coincides with the original mark on the side of the cylinder a second reading is taken. The difference between this and the first reading is the volume of the object.

ADVANTAGES OF THE APPARATUS

Calibration is avoided since the pipette is graduated. If one desires, he may procure a pipette whose graduation has been checked by the U. S. Bureau of Standards. The only calculation necessary is that of subtracting the second reading from the first. The simplicity of the manual operation makes for rapidity of measurement. With practice one can make 20 or more measurements and calculations in 30 minutes.

ACCURACY OF THE APPARATUS

In 9 consecutive observations on the same object, the following results were obtained.

Observation	*Absolute deviation from mean of 1.99 c.c.*
1.90 c. cm.	.09 c. cm.
2.01	.02
2.02	.03
2.08	.09
2.00	.01
1.99	.00
1.98	.01
2.03	.04
1.93	.06

The accuracy may be expressed in terms of the average deviation from the mean, which in this case is .04 c.cm. The amount of deviation may be chiefly attributed to the following:

1. Loss of water.—Water clings to the objects when removed. This may be compensated for by wetting the object and blotting up the excess before inserting it into the cylinder. It is recommended that the original level in the cylinder and the corresponding level in the pipette be checked after every measurement and adjusted when necessary.

2. Air bubbles.—Most of these may be removed by gently shaking the wire stage after the object is immersed.

3. Surface tension of the water.—If parallax is not avoided error in reading due to the meniscus will be recorded. The method of marking the original water level may be improved upon by using a reading telescope or alidade with a horizontal cross-hair. A detergent such as Dreft, may be added to the water to reduce the surface tension.

4. Attempting to measure to .01 c.cm. on a pipette graduated to .1 c.cm., introduces a factor of personal judgment which is subject to variation.

CONCLUSION

The equipment cost a total of 92¢ plus the syringe bulb. It can be put together in a few minutes, and any one can operate it. The parts can be obtained from the stores of any moderately well equipped chemistry laboratory, and no special parts need be made.

Encouragement and suggestions were received from Dr. F. J. Pettijohn, M. S. Chappars, W. Schmidt of the Department of Geology and Dr. J. A. Simpson of the Department of Physics, of the University of Chicago.

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ANNOUNCEMENTS

TRANSLATIONS OF RUSSIAN GEOLOGIC LITERATURE

The Committee on Russian Literature of the Geological Society of America is compiling a list of English translations of Russian Geologic papers and books covering all fields from geophysics to paleontology. Information regarding manuscript translations is desired. It should be sent to the Chairman of the Committee, Ronald K. DeFord, Box 1814, Midland, Texas, or to the Secretary of the Geological Society. Such information will be published in the forthcoming volumes of the Bibliography and Index of Geology Exclusive of North America and the Bibliography of Economic Geology.

THE NATIONAL RESEARCH COUNCIL HAS APPOINTED A COMMITTEE ON GEOPHYSICS, ADVISORY TO THE OFFICE OF NAVAL RESEARCH

Acting upon a request from Admiral Paul F. Lee, Chief of Naval Research, the National Research Council has appointed a Committee of active scientific investigators to advise the Geophysics Branch of the Office of Naval Research regarding scientific and related aspects of their research programs. The Committee is as follows:

Walter H. Newhouse (Chairman), Harry H. Hess (Vice Chairman), Roland F. Beers, Maurice Ewing, Ellis A. Johnson, Lester E. Klimm, William C. Krumbein, William W. Rubey, and J. Frank Schairer.

Dr. R. C. Gibbs, Chairman of the Division of Mathematical and Physical Sciences of the NRC, acts as Administrative Adviser to the Committee, in collaboration with Dr. Arthur Bevan, Chairman of the Division of Geology and Geography.

The Committee held its first meeting on January 7 and 8, 1948, in Washington, D. C. As stated by Dr. Roger Revelle, Head of the Geophysics Branch of the Office of Naval Research, that Branch is charged with the responsibility within the Navy Department of sponsoring basic research in appropriate fields of earth sciences through financial and other support of worthy projects. Functioning within this general framework of responsibility the Committee will, for the present, restrict its consideration to research problems dealing with the crust of the earth and the properties of the earth as a whole.

Since it is part of the policy of ONR to sponsor research in fields not adequately covered by other agencies, the Geophysics Branch, with the Committee's concurrence, has established the following objectives for Research within the fields covered by the Committee:

1. To foster, in cooperation with other agencies, geological, geographical, and geophysical explorations of little known areas of the earth such as the islands of the Western Pacific and the Arctic and Antarctic. Such exploration may include all aspects of the natural environment and problems of human and economic geography and ethnography as well as the more limited objectives implied in the terms geology and geophysics.

2. To conduct laboratory and field studies leading to a greater understanding of the properties and processes existing in the outer hundred kilometers of the earth's crust.
3. To develop instruments and techniques for determination of the earth's properties; for example, universal airborne magnetometer equipment.

The Office of Naval Research has adopted the policy of avoiding formulation, detailed direction, and "farming out" of projects for basic research in the belief that maximum progress and results will be realized if projects for investigation grow out of the ideas and interests of the investigators themselves. The Committee warmly endorses this policy and will seek at all times, through advice and recommendations, to further its operation to the maximum degree possible. The submission of significant and well-organized research proposals will be helpful in this connection.

For further details consult the Office of Naval Research, Navy Department, Washington 25, D. C., or the National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

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